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Photochemical Oxidant Air Pollution Effects on a Mixed Conifer Forest Ecosystem

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16. ABSTRACT

EPA contract 68-03-2442 provided support for three years of the studies to determine the chronic effects of photochemical oxidant air pollutants on a western mixed conifer forest ecosystem. Progress reports were published for years 1974-75 and 1975-76 This report deals with the year 1976-77 and is the final publication on EPA contract 68-03-2442. A computer data bank was partially developed in the early years of the study at the Lawrence Livermore Laboratory and was subsequently revised and moved to the computer at the University of California, San Fransisco. Verification and auditing of datasets is underway and several sets are ready for cross-disciplinary analysis for modeling. Computer simulation programs have been written for some of the subsections. Subsystems which received greatest attention during this study were: major tree species response to oxidant dose, tree population dynamics, tree growth, moisture dynamics, soil chemical and physical properties, tree mortality relative to disease, insects and other factors, epidemiology of forest tree pathogens with emphasis on *Fomes annosus*, cone and seed production, tree seedling establishment, litter production and litter decomposition relative to microfloral decomposer populations. Progress is being made in preparation of models for the purpose of describing the behavior of interlinked subsystems. Since much progress has been made in verifying accuracy of data and of identifying information in the data bank the study of subsystems interaction should be accelerated.

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EPA-600/3-80-002
January 1980

PHOTOCHEMICAL OXIDANT AIR POLLUTION EFFECTS ON A MIXED CONIFER FOREST ECOSYSTEM

Final Report

Editor

O. C. Taylor

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FOREWORD

The San Bernardino National Forest (SBNF) has been under stress from photochemically produced oxidant air pollutants for more than three decades. With the rapid industrial and urban growth in the South Coast Air Basin during the past 20 to 30 years the impact on forest species has intensified. Loss of ponderosa and Jeffrey pine trees has increased dramatically as pollutant levels have risen and frequency and length of pollutant attacks have expanded. Pollutant effects on interrelated subsystems of the SBNF ecosystem have been studied in 18 plots established in selected regions of the forest. The plots were selected to represent sites of varying pollutant dosages while retaining as much uniformity of plant species and environment as possible. Studies by scientists from the Berkeley and Riverside campuses of the University of California collected data which will be used for a group of linked models. The models will aid in describing pollutant impact on subsystems and such models should be useful in anticipating or predicting responses in other areas under similar conditions. Data gathered during the period of this contract will add significantly to information collected under previous contracts and during the subsequent two years of an EPA grant for the purpose of refining the models of a western coniferous forest ecosystem under stress from long-term exposure to photochemically produced air pollutants.

ABSTRACT

EPA Contract 68-03-2442 provided support for three years of the studies to determine the chronic effects of photochemical oxidant air pollutants on a western mixed conifer forest ecosystem. A progress report for the years 1974-'75 and 1975-'76 was published in the Ecological Research Series, EPA-600/-3-77-104. The report being submitted deals specifically with the year 1976-'77 and is the final report for EPA Contract 68-03-2442 which has funded a three year portion of the study initiated in 1972 and is scheduled to terminate May 31, 1980.

A computer data bank was partially developed in the early years of the study at the Lawrence Livermore Laboratory and was subsequently revised and moved to the computer at the University of California, San Francisco. Verification and auditing of datasets is well underway and several sets are now ready for cross-disciplinary analysis for modeling. Computer simulation programs have been written for some of the subsections.

Subsystems which received greatest attention during this study period were: major tree species response to oxidant dose; tree population dynamics; tree growth; moisture dynamics; soil chemical and physical properties; tree mortality relative to disease, insects and other factors; epidemiology of forest tree pathogens with emphasis on Fomes annosus; cone and seed production; tree seedling establishment; litter production and litter decomposition relative to microfloral decomposer populations. Progress is being made in preparation of models for the purpose of describing the behavior of the interlinked subsystems. Since much progress has been made in verifying accuracy of data and of identifying information in the data bank the study of subsystems interaction should be accelerated.

This report in conjunction with the Ecological Research Series report EPA-600/3-77-104 is submitted to fulfill the requirement for a final report for EPA Contract 68-03-2442.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

SCAB -- South Coast Air Basin
SBNF -- San Bernardino National Forest
CP -- Camp Paivika vegetaton plot
BP -- Breezy Point vegetation plot
TUN 2 -- Tunnel 2 vegetation plot
DWA -- Dogwood A vegetation plot
DWB -- Dogwood B vegetation plot
DL — Deer Lick
SF -- Sky Forest vegetaton plot
UCC -- University Conference Center vegetation plot
COO -- Camp O-Ongo vegetation plot
GVC -- Green Valley Creek vegetation plot
NEGV — Northeast Green Valley vegetation plot
SV -- Snow Valley vegetation plot
BL -- Bluff Lake vegetation plot
SC -- Sand Canyon vegetation plot
HV -- Holcomb Valley vegetation plot
CA -- Camp Angeles vegetation plot
SCR -- Schneider Creek vegetation plot
BF -- Barton Flats vegetation plot
CAO -- Camp Osceola vegetation plot
HB -- Heart Bar vegetation plot
PP -- ponderosa pine
JP -- Jeffrey pine
WF — white fir
dbh -- diameter at breast height
ppm -- parts per million

SYMBOLS

μg — microgram
O_3 — ozone

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iii, iv 1	O. Clifton Taylor	Foreword, Abstract, Introduction
3	Ronald N. Kickert Assisted by Robert Thomson	Ecosystem Simulation Modeling
28	Joe McBride	Tree Population Dynamics Subsystem
38	Paul Miller	Oxidant Dose - Canopy Response Subsystem
65	Cliff Ohmart Reviewed by Rick Laven and project to be continued by Rick Laven	Oxidant - Tree Growth
77	Rodney J. Arkley, P. L. Gersper and R. Glauser	Physical and Chemical Properties of Soils and Moisture Dynamics
86	Donald L. Dahlsten	Stand Tree Mortality Subsystem - Bark Beetle Population Dynamics
115	Fields W. Cobb and Robert L. James	Epidemiology of Forest Tree Population
132	Joe R. McBride, Donald L. Dahlsten, and Fields W. Cobb	Cause and Extent of Tree Mortality
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INTRODUCTION

This is a progress report for the final year of a study partially supported by EPA Contract 68-03-2442. This report and a previous report designated as EPA-600/3-77-104 constitute the final report for the three year contract which has supported a multidisciplinary research effort initiated in 1972. The study is expected to terminate May 31, 1980.

This continuing-long term study is an effort to identify and quantify chronic effects of oxidant air pollutants on individual units of a forest ecosystem and to model the interactions between units which are initiated, stimulated or driven by the pollutant impact. The units of the ecosystem selected for study were those considered to be most susceptible to pollutant impact those units which are known to play a very important role in structuring the total ecosystem character. We anticipate that models developed for this study will be useful: to design forest and recreational area management programs; to predict long term changes in ecosystem structure when air pollutants are present; and perhaps to aid in establishing reasonable pollutant standards to protect against serious undesirable changes in the ecosystem.

The forest ecosystem is subjected to numerous stresses which favor the development of some organisms and suppress development of others. Air pollutants represent an additional man made stress in the complex, therefore, any study of long-term chronic air pollutant effect must be accompanied by evaluations of impact from other stress factors. Since the intensity of stress produced by any of these factors varies widely over time and since plant response is affected by interaction of the stress factors evaluation of the air pollutant involvement in ecosystem changes become a very complex study.

The San Bernardino National Forest (SBNF) has been exposed to an increasing annual dosage of photochemical oxidants during the preceding 3 or 4 decades as industrial and urban development in the South Coast Air Basin (SCAB) expanded at a phenomenal rate. Abnormalities, later identified as oxidant air pollutant injury, were causing concern among residents and U.S. forestry officials in the early 1950's. The injury on ponderosa pine was initially thought to be associated with hydrogen fluoride and perhaps other air pollutants released by specific industries which were relatively new to the SCAB. Research during the 1950's largely dispelled this theory and implicated the oxidant air pollutants which are the responsibility of a broad sector of man's activities.

The SBNF, located at the east end of the South Coast Air Basin, is subjected to an ebb and flow of polluted air from the SCAB as the alternate diurnal "pumping" of high desert and marine air through the SCAB occurs.

Typically, during the recognized smog season, air flow during the morning is from the east toward the coastal region; and as the day warms, the flow is essentially reversed to deliver marine air laden with oxidant pollutants to the SBNF.

Evaluation of direct effects of oxidant pollutants in the SBNF has for the most part been confined to the dominant tree species although it is known that a wide variety of species of green plants are adversely affected. These primary producers are critical elements in an ecosystem to provide food and shelter for all other organisms in the system. Chronic injury to the green vegetation may over time significantly change the source of energy, protection and general habitat of numerous consumer organisms. An understanding of changes in plant communities suffering from air pollutant injury is essential if one is to predict the fate of an ecosystem impacted by a growing and changing industrial and urban complex.

This study, including the modeling effort, is based on the assumption that the effect of air pollutants or any other stress element will be ultimately transferred to numerous other units of the ecosystem. It would then be expected that a gradual or insidious but significant change in the ecosystem might be expected.

ECOSYSTEM SIMULATION MODELING OF MIXED CONIFER FOREST UNDER PHOTOCHEMICAL AIR POLLUTION

Introduction

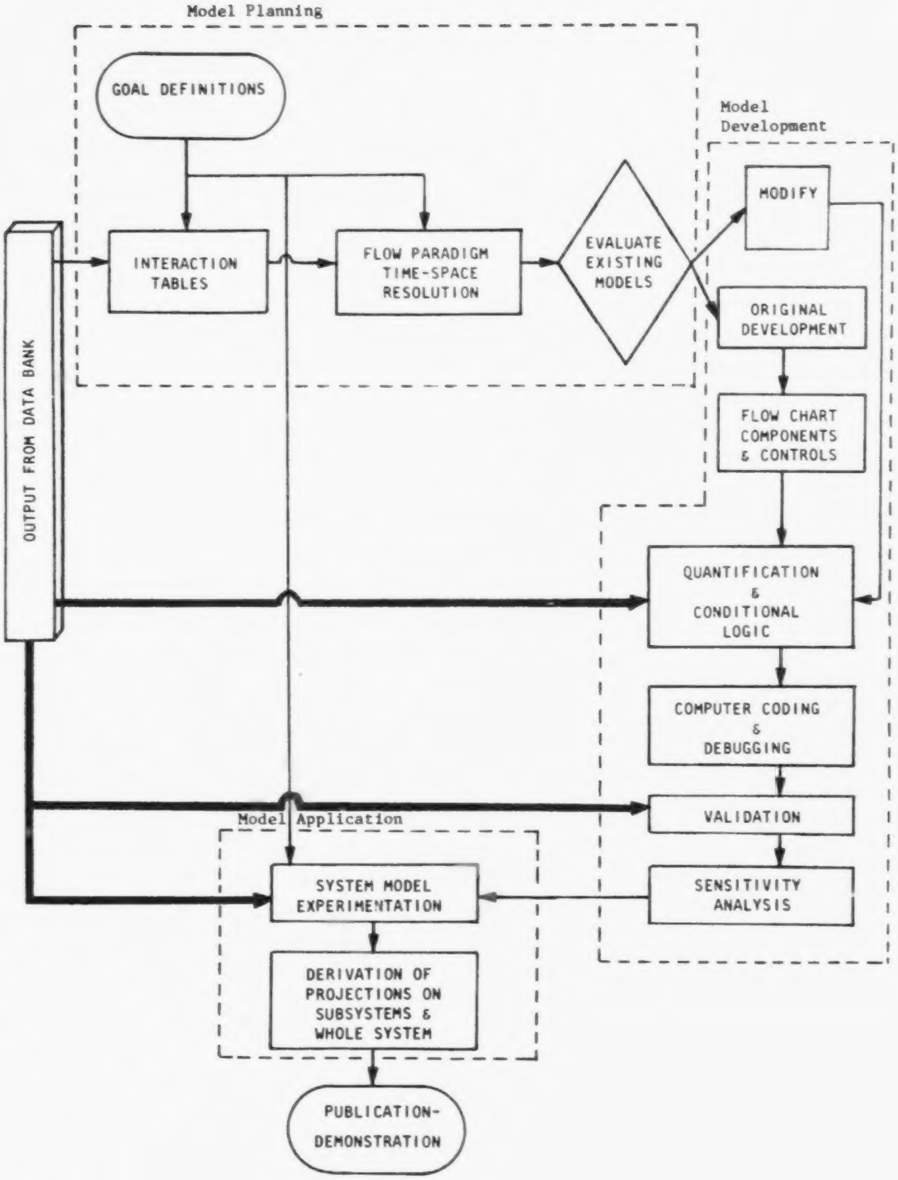
Can experiments be conducted on forest land, using different kinds of long-term air pollution trends to determine ecosystem response, without actual manipulation of the forest, and without decades of waiting for the results? This question leads to the following objectives of the SBNF program: 1) to design forest ecology systems models for forecasting ecological effects of photochemical air pollutants in southern California mixed conifer forest ecosystems; 2) to evaluate the adaptability of systems models to other pollutant types and other forest types; and 3) to evaluate the forecasted consequences of photochemical air pollutants in forest ecosystems in terms of human welfare effects. A discussion of these objectives, together with a review of other scientists' published thoughts related to them, can be found in a previous progress report (Kickert, 1977).

Methods

General systems philosophy and systems analysis techniques involving digital computer simulation modeling methods were applied in working toward the objectives of the project (Figure 1).

System Model Development--

The first step in the development process was to clearly define the various problem solving goals for which the simulation models would be used. This was done by extensive discussion with all project scientists and consideration of the results reported by Kickert (1977). The discussions were directed at drawing out of each investigator a qualitative description of the relations between changeable properties of the forest as a system, as he conceived them to exist in the subsystem(s) pertinent to his major role(s) in the project. The relationships were then diagrammed and integrated into a graphic flow model (Figure 28 in Kickert, 1977). The next step is to convert the set of graphic models into sets of transfer functions to describe annual rate of change expressed as finite difference equations. Conditional logic for threshold and time-delay conditions typical of biological phenomena will be included. The mathematics and associated qualitative conditional logic is written in a high-level computer language. We will then draw upon the project data base, assembled from the data collected by the investigators, and use quantitative relations discovered by them, to refine the mathematical form of transfer functions in the various submodels, to set the values of species and site parameters, and to serve as external data for driving certain functions. Methods of handling the data base are discussed under achievements below because these have been reorganized and



Model Planning
GOAL DEFINITIONS
INTERACTION TABLES
FLOW PARADIGM TIME-SPACE RESOLUTION
EVALUATE EXISTING MODELS
Model Development
MODIFY
ORIGINAL DEVELOPMENT
FLOW CHART COMPONENTS & CONTROLS
OUTPUT FROM DATA BANK
QUANTIFICATION & CONDITIONAL LOGIC
COMPUTER CODING & DEBUGGING
VALIDATION
Model Application
SYSTEM MODEL EXPERIMENTATION
SENSITIVITY ANALYSIS
DERIVATION OF PROJECTIONS ON SUBSYSTEMS & WHOLE SYSTEM
PUBLICATION-DEMONSTRATION

Figure 1. System simulation modeling process with bold arrows showing information flows which were behind schedule and consequently were retarding modeling progress.

re-defined during the period which this report covers.

Model Reliability Evaluation and Use--

After conversion to mathematical computer programs and the essential debugging, the set of simulation programs are run and their behavior is compared to observations of real forests change over a number of years. When this evaluation of reliability is acceptable, we then perform experiments on the simulated forest to determine the probability of long-term responses of various forest properties under alternative future trends in air quality, forest meteorology, and harvesting practices externally imposed on the simulated ecosystem.

Transfer of Ecological Discoveries to Social Scientists--

Results of these experiments are discussed by project investigators and subsequently communicated to scientists outside of the project who are in a position to interpret the economic, social, and political significance as indicated in Table 10 in Kickert (1977). A cost-benefit evaluation of alternative air pollution control strategies in the South Coast Air Basin might possibly be made in agreement with Westman's (1977) warnings by the combined use of this forest simulation package with parts of the MATHAIR (MATHTECH, 1976) computer model and an appropriate meso-scale meteorological transport model. The MATHAIR model assumption for the local source-local impact is not valid for the Los Angeles Basin - SBNF geography.

Documentation is produced for each submodel consisting of a word model description of relationships, graphic flow chart, mathematics, computer program source code, results of reliability evaluation, and results of experiments performed using the forest simulation package.

Dependence of Simulation Modeling on Data Base Management--

Conversion of conceptual models of various subsystems into mathematical algorithms and subsequently into computer programs has been designed to be dependent as much as possible on the many datasets being acquired in the various subprojects of the SBNF program. The data base is designed to serve as documentary evidence for the reality and validity of (1) quantitative relations used to construct the simulation models; (2) the behavior of the set of models when run on the computer; and (3) the kinds of ecosystemsuccession forecasting experiments conducted by using the set of simulators. The bold arrows in Figure 1 outline the broad framework of dependence between the data base and the information requirements for simulator development. Until recently, the lack of a documented and operational procedure for managing the SBNF data base delayed progress in the development of our forest modeling activity.

Discussion of Developments and Achievements During 1976-1977

Progress is described in terms of the sequence of steps being followed in the simulation modeling process presented above and management of the computerized SBNF data base which supports the modeling process. These accomplishments all relate to the first general objective of validating quantitative relations used to construct the simulation models. It is necessary to completely meet this first objective before the second and third can be accomplished. For this reason, we do not yet present results of actual computer experiments using the forest system simulation models for various possible future oxidant air pollution trends.

Organization of Computerized Data Base Management Procedures for Air Pollution Ecological Effects--

Some recent historical perspective is helpful as an aid in presenting the achievements in managing the SBNF data base.

From January 1974, through December 1976, the Corvallis Environmental Research Laboratory and the Lawrence Livermore Laboratory (LLL) had an interagency agreement for the LLL to design and develop a data management system using data collected in the SBNF program.

In late 1975 and early 1976, it became apparent that such a task would not be completed by December 1976, and it was anticipated that the agreement would be renewed for at least an additional year. In August and September 1976, it was discovered that this extension would not take place. In January 1977, the Ecosystem Simulation Modeling subproject acquired the added responsibility of retrieving all of the data files which project investigators had submitted to the LLL, and of organizing a computerized data management system useable on the IBM 370/145 at U.C. San Francisco, The ecological modeling computer work was also being done on this computer. Under the prior arrangement, data management was done on the computer at Livermore, but the change to UCSF led to a significant improvement in model design planning and data management. Both activities could now be done on the same computer system at UCSF. The transfer of responsibility in January 1977, was an abrupt one due to circumstances beyond our control. Clear, comprehensive documentation of the status and contents of datasets associated with the various subprojects was unavailable. These conditions, together with the fact that development of a management procedure for the data base inherited without a budget between January and June 1977, was behind schedule with respect to modeling needs, required us to relax emphasis on model development in order to organize the data base problem.

Dataset verification and auditing-- Although written for a corporate business environment, we applied the philosophy of Wilkinson (1977) in beginning a data processing audit, both through-the-computer, and around-the-computer, for the correction of data sets which we had acquired. We inherited virtually no documentation on the nature of any verification which might have previously been done on individual datasets or between datasets having common cross-referencing data elements, such as tree tag numbers, or species codes.

One objective of the audit was to discover whether datasets which the field investigators assumed we had acquired were missing. Another objective was to uncover discrepancies in data elements between different years for a given dataset, and between datasets where the same data elements were used in each. The intention was to assist field investigators in revealing any errors which reside in the datasets.

The SBNF data base structure: the data dictionary-- The general organizational structure of the data base is shown in Figure 2. A significant achievement has been the establishment of an on-line data dictionary. Schussel (1977) describes this as "a repository of information about the definition, structure, and usage of data. It does not contain the actual data itself" (sic).

We have structured this into a data set index (Table 1), dataset definitions (Appendix 1), and dataset descriptors (example in Figure 3). A computer terminal user can simply log-on, and proceed through these levels of increasing detail of information in search of specific kinds of datasets on ecological effects under air pollution in the forst. This can be done by using the procedure described under the discussion of Centralized Data Base Approach which appears later in this report.

The dataset progress status chart-- There is a sequence of distinct stages through which datasets advance, from the time that the decision is made by a field investigator to collect a certain kind of data, until that time when a written report is produced which contains the description and results of analysis of the dataset. At any given time during this research program, various datasets progress at various rates through all of these stages. Merely tracking down the descriptive information on a dataset by using the data dictionary does not inform one as to whether or not the dataset has reached a stage where the data are presently analyzeable on the computer. In order to assess the status of any of the datasets in the SBNF data base (Figure 2) at a given instant, an on-line Dataset Progress Status file has been established and is updated on a weekly basis. A listing of this file, as of August 31, 1977, is presented in Appendix 2. This feature of the SBNF data base enables us to track the status of a dataset through the various stages of preparation, from left to right in Appendix 2, so that analysis can then be performed, using that dataset. It also allows us to see where we are in terms of stages of a dataset's analysis for systems modeling, for data-sharing among investigators in the project, and subsequently, for external requests for data. Datsets whose entries extend to the right of the vertical bold line in Appendix 2 are ready for, or are presently under analysis. Those that do not are still in a stage of data preparation. The information categories "NEW DATA" and "VERIFICATION" pertain to datasets which have not yet been verified by the original investigator. "FORMAT APPROVED" only pertains to new types of data collection efforts as they may arise. This stage is intended to call to the attention of the investigator that some aspect of his data form format will induce subsequent delays in data processing. If its being altered presents no problem for the logistics of field data collection, he is advised as to what change to make for his benefit later in the data processing stage.

The category "DESCRIPTOR ENTERED?" shows a record of whether that document has been placed in the data dictionary. Appendix 2 shows that a number of datasets have not been covered in this way since we took on this

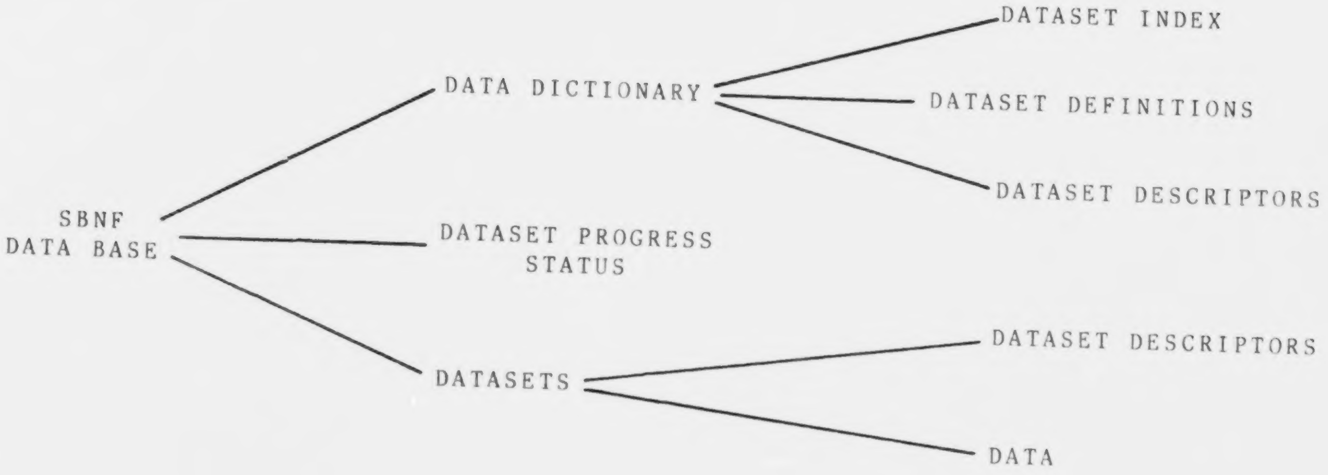

SBNF
DATA BASE
DATA DICTIONARY
DATASET PROGRESS STATUS
DATASETS
DATASET INDEX
DATASET DEFINITIONS
DATASET DESCRIPTORS
DATASET DESCRIPTORS
DATA

Figure 2. Information structure for the computerized SBNF data base accessible from remote dial-up terminal via UCSF/CMS time-sharing mode.

TABLE 1. PART I OF THE SBNF DATA DICTIONARY: THE DATASET INDEX.

age class	STAGE, FIRESTAG, PLOTREGN, CTREE, STNDSITE
air pollutant	OXIDINDX, OXIDANT, PLOTOXID
air temperature	FSMTINDX, FSMET, HMET, PLOTMET
basal area, tree	TREEVEG, SPRMORT1, SPRMORT2, SPRMORX, STNDSITE
cations, soil	SXSCAT
cones	CONE, GCONE
cover	SHRUBVEG, PLOTREGN, PLITR, STNDSITE
crown data, tree	CTREE, SPRMORT1, SPRMORT2, SPRMORX TREEPEST
density, tree	TREEVEG, FIRETREE, SPRMORT1, SPRMORT2
diameter, breast height	TREE, SPRMORT1, SPRMORT2, TREEPEST
disease, tree	DISU, FASP, SPRMORT1, SPRMORT2, STNDSITE, TREEPEST
elevation	PLOTINDX, STNDSITE
fire effects	FIRETREE, FIRESTAG, FIRESRUB
foliage	STOMRES, OZFLUX, TREE, CTREE, SAPTREE, SAPSURF, FLDECOMP
geographic coordinates	PLOTINDX
height, tree	CTREE, SPRMORT1, SPRMORT2, STNDSITE, TREEPEST
height growth, tree	SAPGRO
index	PLOTINDX, FSMTINDX, OXIDINDX
insect risk	TREE, SAPTREE
insects	ISURV, BTREE, EGG, REAR, STIK, XRAY, SPRMORT1, SPRMORT2, SPRMORX, STNDSITE, TREEPEST
litter, needle	PLTR, PNFALL, TREELIT, LITMAS, FLDECOMP, LITRKEM, SLSS
location, tree	TRID
moisture, soil	MOIST, MATRIC, LSOIL
mortality, tree	TREEMORT, TREE, SPRMORT1, SPRMORT2, SPRMORX, STNDSITE, TREEPEST
needle leaf, condition	TREE, SAPTREE
needle leaf, length	TREE, SAPTREE
needle leaf, retention	TREE, SAPTREE
net radiation	FSMET
nutrients	SXSCAT, SFCSOLKM, LITRKEM, DRIP
organic matter content, soil	STEXOM
oxidant, ambient concentration	OXIDINDX, OXIDANT, PLOTOXID
ozone, ambient concentrtion	OXIDINDX, OXIDANT, PLOTOXID, OZFLUX
pH, soil	STEXOM
plot, vegetation-, logistics	PLOTINDX
plot, super-	SPRMORT1, SPRMORT2, SPRMORX, STNDSITE, TREEPEST
plot, sapling-	SAPTREE, SAPGRO, SAPSURF

TABLE 1. (CONTINUED)

precipitation;	HPREC, PLOTPREC, DRIP
publications	EPA/SBNF contracts & grants; SBNFPUBS
radial growth, tree stem	TREEGRO, TREEGRO2, BOGRO, SPRMORX, TREEPEST
regeneration, tree	PLOTREGN, STAGE, CONE, GCONE, PLOTSEED, SAPS, LSOIL, SSAS, SLSS, SPRXRGNS, SPRXRGNC
relative humidity, air	FSMTINDX, FSMET, HMET, PLOTMET
seedling	PLOTREGN, SAPS, STAGE
seeds; see regeneration	
shrub	SHRUB, SHRUBVEG, FIRESRUB, STNDSITE
site	PLOTINDX
slope	TREESOIL, STNDSITE
smog injury score	TREE, SAPTREE, SPRMORT1, SPRMORT2, SPRMORX
soil	SXSCAT, STEXOM, MOIST, MATRIC, TREESOIL, SFCSOLKM, LSOIL, STNDSITE
species composition	TREEVEG
species, tree	TRID
succession	STAGE, PLOTREGN, FIRESTAG, STNDSITE
texture, soil	STEXOM, STNDSITE
tree tag number	PLOTINDX, TRID, TREE, CTREE, CONE, TREEGRO2, BOGRO, DISU, ISURV, TREEMORT, TREESOIL, PNFALL, TREELIT, LITMAS, FLDECOMP, DRIP, LITRKEM, SFCSOLKM, SAPTREE, SAPGRO, SAPSURF
wind direction	FSMTINDX, FSMET, HMET
wind speed	FSMTINDX, FSMET

```
DATASET NAME:  SAPGRO  (PINE SAPLING ANNUAL HEIGHT GROWTH)
INVESTIGATOR: PAUL R. MILLER, U.C. RIVERSIDE, (714)-787-3661
STATUS OF EXTERNAL AVAILABILITY: CLOSED
DATASET DESCRIPTOR AUTHOR/DATE: R.N. KICKERT, FORESTRY, U.C. BERKELEY; 8/5/77
DATA SITES: BL (JEFFREY PINE), BP (PONDEROSA PINE), CA (PONDEROSA PINE),
            CAO, CP, DWA, HB, HV, SF, TUN2;
DATA RECORD SEQUENCE: ONE RECORD PER TREE; RECORDS GROUPED BY PLOT;

DATA ELEMENT SEQUENCE: [X] POSITIONAL,  [ ] FREE-FIELD,  OR  [ ] KEY-IDENTIFIER?
                       [_]              [_]                  [_]
RECORD FORMAT DESCRIPTION: (VARIABLE NAME, COLUMN NUMBERS FOR VARIABLES' FIELDS,
                           PHYSICAL UNITS/ IF ANY/, ESTIMATED OBSERVATIONAL
                           ERROR TOLERANCE)
 1. PLOT INDENTIFIER, COL 1, A(4);
 2. TREE TAG NUMBER, COL 5, F(4);
 3. ANNUAL INTERNODE LENGTH GROWTH, COL 9, 18(1X,F3.0),  MILLIMETERS, +/- 30 MM;

DATA COLLECTION DATES:   1976;
NOTES, QUALIFICATIONS, LIMITATIONS (BY VARIABLE NAME):
 2. INFORMATION ON SPECIES, EXACT LOCATIONS,  1975 TOTAL TREE HEIGHTS, STEM
    DIAMETERS, AND ANNUAL CROWN CONDITION, FOR EACH TAGGED SAPLING CAN BE
    FOUND IN THE DATASET NAMED 'SAPTREE';
 3. FROM LEFT TO RIGHT, ALONG THE RECORD, A MINIMUM OF 10 INTERNODE LENGTH
      VALUES CORRESPOND TO THE YEARS
    1976, 1975, 1974,... 1967.  ADDITIONAL VALUES, UP TO A TOTAL OF 18 VALUES,
    MAY BE FOUND IN A SINGLE LOGICAL RECORD, WHERE THE 18TH VALUE CORRESPONDS
    TO THE YEAR 1959. THE VARIABLE RECORD LENGTHS PRIOR TO 1967 ARE A RESULT
    OF THE INVESTIGATORS GOING BACK ONLY AS FAR AS THEY FELT THEY COULD
    ACCURATELY DETERMINE ANNUAL INTERNODE INCREMENTS.

*******************************************************
```

Figure 3. Example of Part III of the SBNF Data Dictionary: Dataset Descriptors.

activity. If the category "KEYPUNCHED?" contains an "N" for a dataset, then we have not been given a card deck for that dataset by the respective investigator. The category "REDUCTION PLAN DEFINED?" refers to whether a specific detailed plan for quantitative analysis of the dataset has been defined for the purpose of identifying certain transfer functions in one of the subsystem models, or for the purpose of evaluating the reliability of a part of the modeling package.

The datasets-- The third portion of the SBNF Data Base structure (Figure 2) is the collection of datasets. Each one is a file stored on magnetic disk, with a back-up copy on magnetic tape, and has a copy of its descriptor located at the beginning of the file.

Centralized data base approach-- The orientation used in maintaining the SBNF data base has been a centralized approach in that all datasets are kept collectively on only one computer system, the IBM 370/145 at the University of California, San Francisco (Medical Center). Within the Ecological Modeling and Data Management activity, the data manipulation environments are diagrammed in Figure 4. Datasets are read in from card decks to magnetic disk under the OS (Operating System) environment and transferred to magnetic tape as backup. The datasets are transferred from OS disk to mini-disk in the Conversational Monitor System (CMS) environment in preparation for work. CMS is a general purpose time-sharing system operating under VM/370. In addition to the datasets which are under immediate use, other units of the SBNF data base such as the Data Dictionary and Progress Status are maintained on CMS mini-disk for immediate telephone access. These relationships are diagrammed in Figure 4. In keeping with the dependence discussed earlier (Figure 1) of ecological systems modeling on analysis of datasets in the SBNF Data Base, model development is conducted in the same CMS environment, including storage of the computer programs designed to simulate various subsystems. To dial up and interact with the datasets in CMS, we use a DataMedia model 1520A video screen, key board terminal, a Diablo 1620 HyTerm printer terminal, and an Execuport 320 portable thermal printer terminal.

Readily available CMS commands can be used to manipulate dataset files and the contents within files. Rapid manipulation of data between datasets can easily be done byusing the CMS commands shown in Table 2. Just about any kind of searches desired can be made on data within a given dataset with commands as shown in Table 3 which are immediately available at the terminal in the TECO and CANDE interactive time-sharing environments on the DEC PDP-10 and Burroughs computers respectively. This means that any eventual use of the SBNF data base on other main frame computers elsewhere, perhaps by other environmental scientists, should be just as useable as our capability on the UCSF IBM computer.

Aside from using the CMS commands for retrieved and displayed various kinds of data, summarization and analysis of data are done by entering either the SPEAKEASY mode or SPSS mode in the on-line environment, or by submitting a batch job, via remote job entry, in OS to use the BMDP statistical programs (Figure 4). SPEAKEASY is a simple interactive data manipulation language containing an immense number of built-in functions for

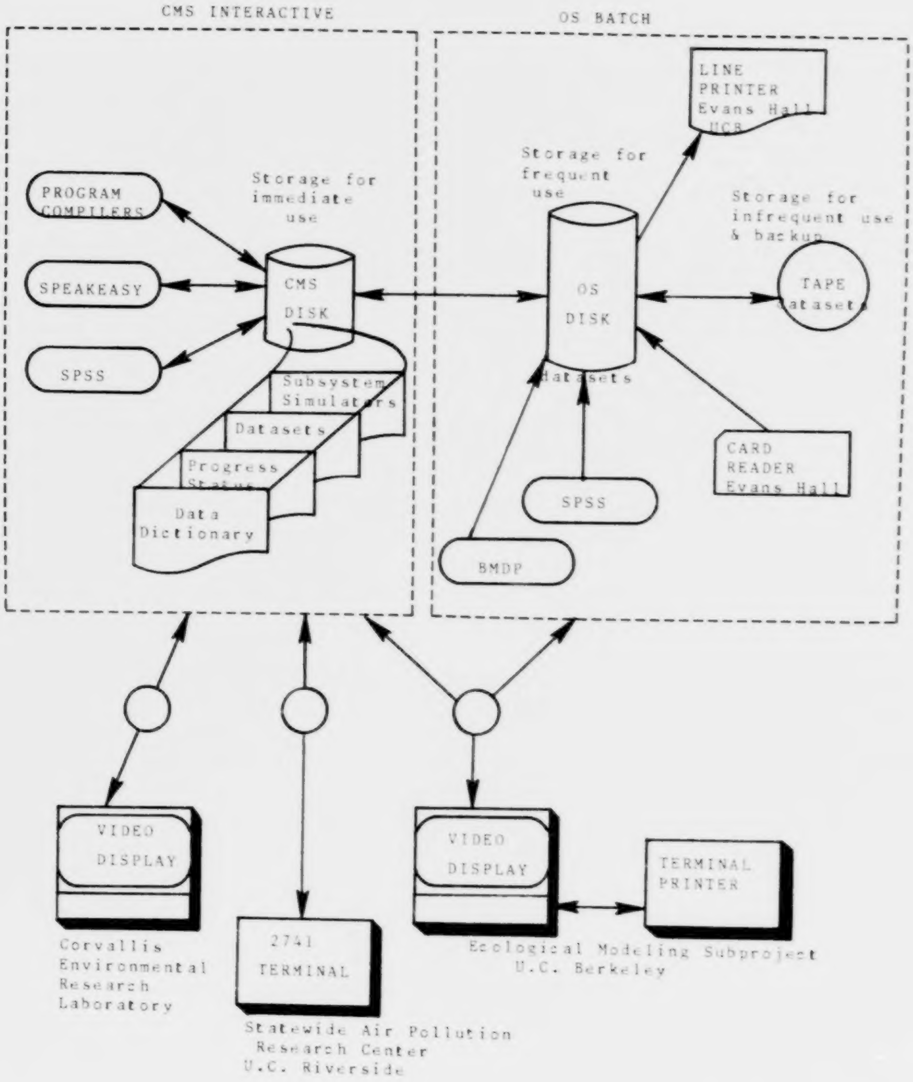

CMS INTERACTIVE
OS BATCH
PROGRAM COMPILERS
SPEAKEASY
SPSS
Storage for immediate use
CMS DISK
Subsystem Simulators
Datasets
Progress Status
Data Dictionary
LINE PRINTER Evans Hall UCB
Storage for frequent use
OS DISK
Datasets
Storage for infrequent use & backup
TAPE Datasets
CARD READER Evans Hall
SPSS
BMDP
VIDEO DISPLAY
Corvallis Environmental Research Laboratory
2741 TERMINAL
Statewide Air Pollution Research Center U.C. Riverside
VIDEO DISPLAY
TERMINAL PRINTER
Ecological Modeling Subproject U.C. Berkeley

Figure 4. Data processing environments used for simulation modeling and data base manipulation on IBM 370/145 computer at University of California, San Francisco, via 30 cha_acter-per-second telecommunications.

TABLE 2. CMS TIME-SHARING COMMANDS USED FOR ON-LINE FILE MANAGEMENT OF SBNF DATA BASE.

Command	Function
EDIT	construct a new file by inputting through the terminal, or change, or examine data within, an existing dataset file (see TABLE 3);
READCARD	construct a new file by reading a card deck;
COPYFILE	combine several files into one file; rearrange the contents of records in a file; add one file to the end of another;
RENAME	change the name of a file;
TYPE	type the contents of a file on the printer at Evans Hall on the UCB campus;
PRINT	type the contents of a file on the printer at Evans Hall on the UCB campus;
COMPARE	compare all or part of the records in two files and type the records that are not identical;
LISTFILE	list information about the files which are stored on disk;
ERASE	delete the specified file from disk.

TABLE 3. CMS TIME-SHARING EDIT-ENVIRONMENT COMMANDS USED FOR FINDING, CORRECTING, AND DISPLAYING THE CONTENTS OF A DATASET OR PROGRAM FILE IN THE SBNF DATA BASE.

Command	Function
INPUT	creates new lines typed into the file by the user at the terminal
LOCATE	locates the next line in the file that contains a specified character string (and types the line at the terminal)+
TOP	moves the line pointer back a specified number of lines in the file
UP	moves the line pointer back a specified numbr of lines in the file
BOTTOM	moves the line pointer to the position following the last line in the file
DOWN	moves the line pointer forward a specified number of lines in the file
NEXT	moves the line pointer forward one line (and types the line at the terminal)+
CHANGE	changes a specified character string in the line to a new character string; can be used to search for a specified character string anywhere in the file and then type out the line in which the string is found
REPLACE	changs the current line content according to the terminal user's request
DELETE	beginning at current line, erases the specified number of lines from the file
TYPE	beginning at current line, types out the contents of the specified number of following lines in the file
FILE	terminates the current editing session for the file and stores the file on disk

+ assuming VERIFY command is ON

performing mathematical and statistical analyses on data arrays and vectors, for manipulating arrays in various ways, and for graphing data. SPSS is the Statistical Package for the Social Sciences which is documented in Nie et al. (1975). BMDP is the set of statistical analysis programs documented in Dixon (1975).

While our base of operations is at U.C. Berkeley, we have easily accessed, with no difficulties, the various units of the SBNF Data Base just described, and some of the simulation programs, while at the Statewide Air Pollution Research Center, U.C. Riverside, and the Corvallis Environmental Research Laboratory, Corvallis, Oregon. The potential exists for any investigator in the SBNF program to directly interact with the UCSF computer with those datasets that have been verified. The extent to which this happens from now on depends upon the desires and motivations of the investigators.

Distributed processing approach-- While a centralized approach to maintaining the SBNF data base has been employed, the approach to processing of datasets has evolved in a distributed manner. Up to the present, several investigators in the project have only operated on their own datasets within their own data processing environments. This is evident in our assessment, as shown in Table 4, of the amount of data processing which has been done by investigators on computer systems other than the one used to maintain the centralized SBNF data base since January 1977, and the distribution of data-related requested from the investigators to this subproject. Project investigators haven't reached the stage of conducting integrated data analysis of their own datasets with those assembled by their colleagues. This is probably because not enough years of data had accumulated prior to this time and also because the entire data base was not in a readily accessible computer environment. In addition, it is natural that we will be doing much of this for transfer function identification in system model development. As the project approaches a stage of synthesis in the next few years, a decision may be adviseable from the project investigators as to whether it is in their best interest, from the viewpoint of trans-disciplinary data analysis, for them to continue solely with a distributed data processing approach.

Specific data processing tasks achieved-- In 1973, the Soils subproject placed soil moisture sensors at various depths on 22 sites in the 18 vegetation plots. These have been interrogated at weekly, or biweekly, intervals since that time by personnel out of U.C. Riverside. The Soils subproject also took field soil samples to the laboratory to develope calibration data so that the field data on electrical current passing through the moisture sensors could be converted to log resistance values and then to percent soil water values. Data processing to accomplish these steps was expected to be finished under the previous EPA/LLL agreement during January 1974, through December 1976, as discussed earlier in this report. The fact that this did not materialize precluded the avilability of percent soil water data and essentially halted progress in further development of our forest stand moisture simulation model. In the first half of 1977, we tackled this deliquent data processing task and by August 1977, the establishment of the MOIST (reduced) dataset was 95 percent accomplished.

TABLE 4. STATUS OF DISTRIBUTED VERSUS CENTRALIZED DATA PROCESSING OF SBNF DATA BASE FOR VARIOUS SUBPROJECTS AS OF AUGUST 1977.

Submodel	Relevant investigator	Independent data processing	Dependence on data management subproject
WATER	Arkley	little	much
CANOPY	Miller	much	little
TREEGROW	Laven	little	much
ROOTS	Cobb	some	some
BEELTE	Dahlsten	much	some
mortality	superplot	little(?)	much(?)
LITTER	Arkley/Miller	some	much
LITDECAY	Bruhn	some	much
CONE	Luck	some	some
SEEDLING	Cobb	much	little
	McBride	much	little
STNDCOMP	McBride	much	little

Another task achieved was the conversion of raw field data on plot tree ring widths (TREEGRO dataset) obtained as far back as 1920, to a form which is now useable for analysis in developing the tree STEM growth subsystem simulator.

Accomplishments in auditing datasets--In order to prepare the Data Dictionary and Data Progress Status Chart, our audit of the datasets led to results which in some cases revealed further data needs for modeling, and in other cases led to improvements in the consistency of information within and between datasets.

By auditing the data elements in SPRMORT1, SPRMORT2, SPRMORX, STNDSITE, and TREEPEST, we discovered that data were not being obtained that would enable calculation of the stand tree mortality as a percentage of the total stand stocking density, by species. We would have the estimates of numbers of recently killed trees, by apparent causal agents and by species, but we would not be able to relate this to the population size of the stand at the superplot spatial scale. This deficiency would hinder the evaluation of reliability of the systems models.

The audit of data elements also revealed that we were not going to obtain the kind of dead tree data necessary to tell the computer how to kill a tree in a biologically reasonable way during simulation. Subsequently, the data elements shown in the SPRMORX dataset (see Appendix 1) were defined for field data collection. These include, for each mortality center dead/damaged tree, recent radial growth increments, and height to lowest branch bearing needles.

Additional supplementary datasets became identified as needing to be established in the SBNF data base. These include SBNFPUBS, PLOTINDX, FSMTINDX, OXIDINDX, and PLOTSEED. A description of each of these is found in APPENDIX 1.

Several cases resulted in improvement in consistency of dataset contents. Since several different datasets contained species identification and tree tag numbers, we ran a program to compare for taxonomic agreement across all the datasets, tree-by-tree, for all vegetation plots, and had a list printed of any and all disagreements. The need to verify agreement between datasets on this data element was fundamental in order to proceed with any other tree-related data analysis. When the task was done, it became evident that several datasets from various years and/or different investigators contained discrepancies as to the taxonomy to be associated with a given tree number. Two major reasons for these discrepancies seemed to be the degree of hybridization which occurs in some areas between ponderosa pine, Jeffrey pine, and Coulter pine, and the problem of mis-reading the tag number of a tree when making and recording observations. Several project investigators subsequently used these lists in the field to recheck specific trees and plots, which led to improved consistency of data in TRID, CTREE, TREE, DISU, ISURV, and TREEGRO datasets.

For both years, 1974, and 1976, of the Disease Survey (DISU) dataset, a comparative listing was made by the computer, tree-by-tree, for any differences in the data entries for a given tree between the two surveys. The results were returned to the plant pathology subproject for resolution of inconsistencies.

Other internal examinations of TRID and TREE led to enhancements in their contents.

Summary of data base status-- We have used the Dataset Progress Checklist (Appendix 2) to assess the present overall state of the project data base. Table 5 contains a summary of the findings. The proportion of the data base in various stages indicates that we are ready to concentrate more on cross-disciplinary data analysis for modeling in the next year than has been possible since data collection began four years ago. However, we urge the subproject leaders to make sure they prepare and submit verified card decks as soon as possible following data collection, so that joint analysis between their subprojects and the Ecosystem Modeling subproject can be done with a minimum of delay.

Developments in Ecological Subsystem Modeling--

A previous report (Kickert, 1977) highlighted the interrelational structure between various submodels being developed. A population dynamics accounting (STNDCMP) for trees in the forest stand is driven by submodels dealing with tree regeneration (SEED, SEEDLING, LITTER, LITDECAY) and stand mortality (ROOTS, BEETLE). Each of these model subsets is driven by a stand moisture subystem (WATER), as well as by external inputs of air quality monitoring data (OXIDANT dataset and PLOTOXID dataset).

In Figure 1, the first important link for use of the project data base in the modeling activities is evaluating the quantitative nature of the relations which have been hypothesized in the flow chart of the various ecological subsystems (Kickert, 1977). A computer subroutine is being written to simulate each subsystem is in the process. The sequence in which each of the various subroutines will be activated on the computer, for passing information from one simulated subsystem to another, is shown from left to right in Figure 5. Prior to the computer terminal user telling the simulators to begin running, the user is first given a series of options for running the simulation. These options are for setting numerical values for: starting year and ending year; site and tree species parameters which will not change during the simulation; initial forest stand conditions; the nature of long-term trends in meteorological conditions which the user wants to drive the simulation; and the format of the output display to be used. All of these options have default choices built-in, with the additional option of being able to display the default values at the terminal, so the user may avoid making decisions to override these if so desired. Figure 5 also shows which of the datasets, listed in Table 1 and Appendix 1, are being, or will be, used to quantify relations in each of the subsystem models, and which will be used to provide the external physical environmental data to drive the set of simulators.

Computer simulation programs have been written for WATER, TREEGROW, and partially for BEETLE. Details of the CANOPY submodel structure have

TABLE 5. DISTRIBUTION OF DATASETS BY DEVELOPMENT STAGE FOR THE SBNF DATA BASE AT UC BERKELEY.

Development stage+	Number of datasets	Percentage of data base
1A. Descriptor not yet written for Data Dictionary++	49	79
1B. Dataset not yet key-punched (or converted)#	30	48
2. Dataset card deck entered but not yet verified	16	26
3. Dataset verified and corrected on disk##	10	16
4. Dataset presently in analysis for modeling within the Ecological Modeling - Data Mgmt subproject	6	10

+ does not pertain to updates for post-January 1977, for prior existing datasets, but does include new datasets through August 1977;

++ this stage is not mutually exclusive as the subsequent stages are, so it should not be compared against them;

# raw data converted to a new form, or transferred from the U.S. Forest Service to the SBNF data base;

## some datasets counted in this stage may be in the next stage at UC Riverside.

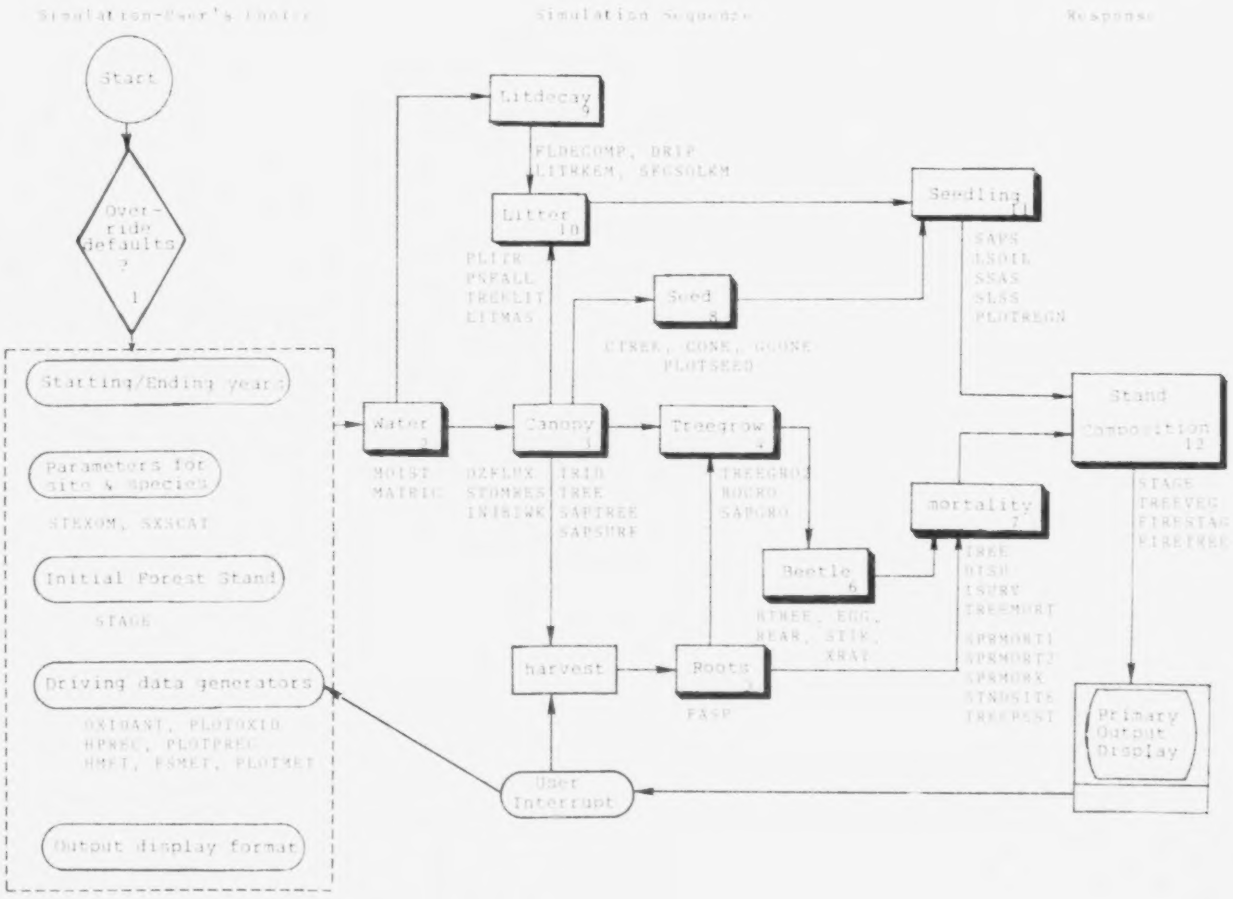

Simulation-User's Choice
Simulation Sequence
Response
Start
Over-
ride
defaults
?
1
Starting/Ending years
Parameters for
site & species
STEXOM, SXSCAT
Initial Forest Stand
STAGE
Driving data generators
OXIDANT, PLOTOXID
HPREC, PLOTPREC
HMET, FSMET, PLOTMET
Output display format
Water
2
MOIST
MATRIC
Canopy
3
DZFLUX
STOMRES
INISIWK
TRID
TREE
SAPTREE
SAPSURF
Treegrow
4
TREEGRO2
ROGRO
SAPGRO
Litdecay
9
FLDECOMP, DRIP
LITRKEM, SFCSOLKM
Litter
10
PLITR
PSFALL
TREELIT
LITMAS
Seed
8
CTREE, CONE, CCONE
PLOTSEED
Seedling
11
SAPS
LSOIL
SSAS
SLSS
PLOTREGN
Beetle
6
RTREE, EGG,
REAR, STIK,
XRAY
mortality
7
TREE
DISH
ISURV
TREEMORT
SPRMORT1
SPRMORT2
SPRMORX
STNDSITE
TREEPEST
harvest
Roots
5
FASP
User
Interrupt
Stand
Composition
12
STAGE
TREEVEG
FIRESTAG
FIRETREE
Primary
Output
Display

Figure 5. Simulation sequence between subsystems (numbered rectangles), showing associated datasets (capitalized) for submodel quantification and validation.

been worked out, and the next step will be to convert it into program code. ROOTS, LITDECAY, LITTER, SEED, and SEEDLING subsystems should have the first versions of the simulation programs written in the next six months.

The stand moisture subsystem simulator-- The WATER submodel is used to take precipitation and air temperature data, and simulate biweekly changes in soil water in the tree root soil depth. This is then used as input to the CANOPY subsystem, along with ambient oxidant air pollution data. The WATER submodel was a modification of that reported by Sollins et al. (1976) from the Coniferous Forest Biome. We ran our version on the computer and found it to behave in an intuitively reasonable fashion. Further work in adapting this submodel to the southern California forest sites had to be postponed because of unavailability of moisture data and the entire data base problem encountered during the past year. Because of the data base achievements described earlier in this report, we are now in the position to resume development and application of this subsystem model to our needs and goals. A new detailed flow chart was constructed for the logic of this submodel. The one supplied by the authors of the original model (Sollins et al., 1974) was too general to clearly portray the model's relations in the midst of critical review sessions with the soils subproject investigator.

The tree stem growth and canopy subsystems simulators-- A second example of our effort to build on the work of our colleagues elsewhere is found in our subsystem simulators for tree canopy changes and tree stem growth. We analyzed the structure of a forest succession simulator, called SUCSIM, developed in the Coniferous Forest Biome. Reed (1976) has described the theoretical ecology foundation for the model, and has documented the mathematical details of the various functions (Reed and Clark, 1976). This model was developed as an adaptation of the basic tree growth theory earlier developed in the easterb United States for deciduous forest systems simulation by Botkin et al. (1972). In contrast to the many mensurational forest growth models based on site-index, Reed's simulator has trees grow in response to physiological definition of tree species niches, with regard to availability of needed environmental resources for growth, light, heat, moisture and nutrients. Because of this particular theoretical base, this model appears more suitable for restructuring for the study of growth effects of environmental pollutants than do other tree growth models.

The structure of the Reed model can be viewed as consisting of two modules relating to individual tree growth, a crown module, and a stem module. These feed into three modules at the tree population or stand level, a population regeneration module, a population mortality module, and a population update module. The primary variables which describe the state of the system in this model at any time are basal diameter of individual trees, height of individual trees, total leaf biomass of individual trees, age and species of individual trees, diameter at breast height of individual trees, and number of live trees in the population. The only state-variable, and respective mathematical functions, in this list for which we presently have no data in the SBNF data base are those related to leaf biomass.

We have assembled the computer code for Reed's stem module as our

TREEGROW subsystem, and are restructuring his crown module to respond to air pollution injury so we can use the modified version as part of our CANOPY subsystem. We are revising his simplified population regeneration and mortality modules since the SBNF program was designed to investigate and model these processes at a higher resolution (SEED, SEEDLING, LITTER, LITDECAY, and ROOTS, BEETLE). What we have identified as his population update module is similar to our STNDCMP subroutine. This is the master calling procedure that keeps account of how many trees of various ages and species exist at any given time during the simulation.

Quantification of site and species parameters and transfer functions-- As indicated under the previous discussion on the progress status of datasets, we have now organized the data base sufficiently to move more into quantitatively analysis of transfer functions for the various submodels. Our audit of the datasets and simulataneous conceptual development of submodels has led to the discovery that certain kinds of analyses are possible and data collection techniques are available that could improve the quantification process for various subsystem models.

A design of foliar biomass analysis for trees under varying degrees of oxidant air pollutant injury is suggested to improve useability of the tree stem growth submodel. Functions in the original stem growth simulator now used were constructed for essentially pollution-free forests. This analysis is necessary to couple the oxidant-foliar injury submodel (CANOPY) with the tree growth submodel (TREEGROW).

Development of the oxidant-uptake and crown foliar injury submodel is designed on the hypothesis that changes in transpiration affect the amount of oxidant taken into leaf tissue and the subsequent visible injury found over long periods. We suggest that the appropriate investigator strongly consider an experimental treatment on pine foliage to demonstrate the degree of validity of this hypothesis. This suggestion involves repeatedly treating samples of new foliage, during Spring-time, at a known heavily polluted site, to applications of an antitransparent, and then following the seasonal changes in the various foliar injury symptoms typically associated with ambient oxidants.

To apply the stand moisture simulator, WATER, to forest plots in the SBNF, so that the hypothesis on transpiration control of oxidant uptake may be simulted, we suggest that the soils subproject strongly consider performing a hammar seismograph analysis to determine the maximum soil depth on those vegetation plots where this information is not already available as a result of the past installation of soil moisture sensor profiles.

For a part of the organic LITTER dynamics submodel which responds to the oxidant uptake crown injury subsystem, we suggest that the appropriate investigator consider getting data on: 1) the distribution of various areal densities of coarse woody litter on the ground on vegetation plots; and 2) the time rate of change of the amount of woody matter which falls from various tree species after individuals are killed by a pest complex.

Design of approach for evaluation of reliability of the simulation package--With regard to the simulation models developed in this project, the project officer has advised that the stage at which the Corvallis Environmental Research Laboratory desires to receive information is with the documentation of the reliability of the models as compared to actual real forest response. Reliability of the models can be examined using a method of successive approximation. An easier, but less objective, method is to obtain "the reactions of experienced field observers to the predictions" of the simulation package (Botkin et al. 1972). A more objective, but more difficult, method is to run the simulation with historical input data and to compare the computer model output behavior with historical data on the same output variables.

In some cases, there appear to be adequate types of data for evaluating the reliability of individual submodels, such as WATER and CANOPY, over the relatively short-term study period 1973 through present. However, we are convinced that the reliability of the entire linked set of subsystem simulators, producing simulated annual output on numbers of trees by species by age, can only be evaluated over a long time span of data. If we knew what the tree species composition on the vegetation plots were in 1920 and 1950, we could initialize the simulation package for 1920, and using historical weather data from HPREC and HMET datasets (Appendix 1), run the simulators to 1950, covering the recent pre-air pollution era. We could then compare simulated forest tree species composition at "1950" on the computer with the actual 1950 known composition. By using quantitative techniques developed by Miller for reconstructing the increasing oxidant air pollution trend from 1950 to 1973, and using monitored data for 1973 through present, we could run the simulators for the air pollution era and compare simulated forest species composition at "1973" through "present" on the computer with the known field composition data for the same years. For the latter, the datasets STAGE and TREEVEG, collected in 1973, are in the SBNF data base. Assuming these reliability evaluations showed that the simulators tracked the field data closely enough for 1950 and the mid-1970's to preclude the decision that the models' behavior were unreliable, then we could begin using the simulation package to perform "what if..." experiments (Figure 1 herein, and 26 in Kickert (1977)) on the computer for the future period 1980 through 2025. We are using the philosophy that one cannot directly prove that a simulation model is relizable; one can only fail to show that it is unreliable, the initial a priori assumption, after repeated attempts to discover the unreliable behavior.

All investigators in the SBNF project must be aware that the ultimate usefulness and acceptability of all of the subsystem simulators and acceptability of all of the subsystem simulators to outside users, including the Corvallis Environmental Research Laboratory, pivots on our ability to evaluate the reliability of the simulators produced in this program. Inability to evaluate reliability could lead to future potential users regarding these ecological system simulators as simply academic exercises.

At present, the research design does not include obtaining the right kind of numerical data on the SBNF which would allow for evaluating the reliability of the simulation models over the time span 1920 through 1950 (the clean air era), and into 1950 through 1970/80 (the present air pollution era).

In order to evaluate reliability of the simulation package for prospective users, we urge the vegetation investigators to consider collecting data, for the 18 permanent vegetation plots, on tree stump and snag locations, species, diameter, year of death or cutting, and age when death or cutting occurred. These data are needed for synthesis with the stand age data (STAGE in Appendix 1) collected in 1973, in order that reliability analysis can be performed as objectively as possible.

CONCLUSIONS

The project officer has advised that the stage at which the Corvallis Environmental Research Laboratory desire to receive information on simulation models developed in this project is with the documentation of reliability of the models as compared to actual real forest responses. Reliability of the models can be examined using a method of successive approximation. The easiest, but least objective, method is to obtain "the reactions of experienced field observers to the predictions" of the simulation package. A more objective, but more difficult, method is to run the simulation with historical input data and to compare the computer model output behavior with historical data on the same output variables. At present, the research design does not include obtaining the kind of numerical data on the SBNF which would allow for evaluating reliability of the simulation models over the time span 1920 through 1950 (the clean air era), and the 1950 through 1970/80 (the present air pollution era). In some cases, there appear to be adequate types of data for evaluating reliability of individual submodels.

The proportion of the SBNF Data Base in various developmental stages indicates that we are ready to concentrate more on cross-disciplinary data analysis for model development in the next year than has been possible since data collection began in the SBNF project 4 years ago.

RECOMMENDATIONS

Planning Future Project Activities In Manuscript Preparation

For purposes of planning data processing tasks and associated manuscript preparation by the project investigators, we suggest that the principal investigator, in consultation with subproject leaders, define all of the research activities felt to be necessary, and all of the manuscripts contemplated, within this program during June 1978 through May 1980.

Reliability Evaluation of Ecosystem Simulation Submodels

In order to evaluate the reliability of the simulation package for prospective users, we urge the vegetation investigators make every effort to collect data, from the 18 permanent vegetations plots to show: tree stump and snag locations, species, diameter, year of death or cutting, and age when death or cutting occurred. These data are needed for synthesis with the stand age data collected in 1973, in order that reliability analysis of the simulation models can be performed as objectively as possible.

Development of Ecosystem Simulation Submodels

For usability of the tree stem growth submodel, we suggest that a foliar biomass analysis be designed for trees under varying degrees of of oxidant air pollutant injury. The functions in the original stem growth simulator being used were constructed for essentially pollution-free forests and analysis is necessary to couple the oxidant-foliar injury submodel with the tree stem growth submodel.

Development of the oxidant-uptake and crown foliar injury submodel is designed on the hypothesis that changes in transpiration affect the amount of oxidant taken into leaf tissue and the subsequent visible injury found over long periods. We suggest that the appropriate investigator strongly consider an experimental treatment on pine foliage to demonstrate the degree of validity of this hypothesis. This suggestion involves repeatedly treating samples of new foliage, during Spring-time, at a known heavily polluted site, to application of an antitranspirant, and then following the seasonal changes in the various foliar injury symptoms typically associated with ambient oxidants.

In order to apply the stand moisture simulator to forest plots in the SBNF, so that the hypothesis on transpiration control of oxidant uptake may be simulated, we suggest that the soils subproject strongly consider performing a hammarseismograph analysis to determine the maximum soil depth on those vegetation plots where this information is not already available as a result of the past installation of soil moisture sensor profiles.

As a part of the organic litter dynamics submodel which responds to the oxidant-uptake crown injury subsystem, we suggest that the appropriate investigator consider getting data on 1) distribution of various areal densities of coarse woody litter on the ground on vegetation plots, and (2) the time rate of change of the amount of woody matter which falls from various tree species after individuals are killed by a pest-stress complex.

For the datasets to be submitted to the Data Management subproject, we urge subproject leaders to make sure that they prepare and submit verified card decks as soon as possible following data collection, so that joint analysis between their subprojects and the Ecosystem Modeling subproject can be done with a minimum of delay.

Interested Cooperating Agencies

The funding agency should recognize and act upon the need of the systems ecologist to have as clear a definition as possible of the ways in which the funding agency could use the information being sought from the research project. It is recommended that the project systems ecologist, agency project officer, and other informed agency personnel obtain a conceptual information flow model describing how the environmental information (data base, computer models, and ecological insights) resulting from this research can be made available. Through a computerized information transfer, delivery could be made to other environmental scientists, administrators, legislators, and interested general public, for the purpose of evaluating secondary standards for photochemical air pollutants, determining possible consequences of alternative ambient oxidant trends, and identifying alternaive forest management practices.

Research proposals which indicate that a variety of different kinds of related data collection is planned by more than one investigator, should be required to show evidence in the proposal that a usable data base management system and data dictionary processor are already available and will be used at the time that data begin to accumulate. This should expedite the rate at which collected data are analyzed.

TREE POPULATION DYNAMICS SUBSYSTEM

Introduction

Environment and particularly stress strongly influence successional change in plant communities and contribute significantly to structure the composition of these communities. Photochemical oxidant air pollutants are stress factors which invade the San Bernardino National Forest (SBNF) and may play an important part in directing successional changes. A gradient in air pollutant exposure is recognized in the SBNF and differential susceptibility of plant species to the pollutants has been demonstrated. Therefore, it can logically be hypothesized that the oxidant air pollutants may strongly influence successional change and through years or decades of exposure may be an important factor in determining plant community structure.

The vegetation subsystem project is focused on describing: 1) plant communities within the mixed conifer forest type in the San Bernardino Mountains, and 2) the impact of oxidant air pollutant on successional changes in these communities. Initial characterizaton of major plant communities has been reported by McBride (1977). This report summarizes two studies conducted during 1976-77 of community description and successional change. One study was designated to identify sub-units (facies) occurring within major plant communities and the second was aimed at classification of forest sites as a first step in the description of plant succession.

Research Objectives

1. To identify and map facies within the plant communities dominated by yellow pines in the San Bernardino mountains.

2. To classify sites within the Jeffrey pine dominated forests of the San Bernardino Mountains on the basis of environmental parameters.

Literature Review

Variation in forest composition in the San Bernardino Mountains has been discussed by Horton (1960), Minnich et al (1969), Miller and McBride (1973), McBride (1973), and McBride (1977). These authors identified a variety of forest communities at the association level (Braun-Blanquet, 1932). The classification developed by McBride (1977) established five associations within the general yellow pine types: ponderosa pine forest, ponderosa pine-white fir forest, ponderosa-Jeffrey pine forest, Jeffrey pine forest, Jeffrey pine-white fir forest, but these associations have not previously been subdivided into facies.

Forest succession in the San Bernardino Mountains was discussed in general terms by Miller and McBride (1973), McBride (1973), and McBride (1977). Wildfire was determined by these authors to have an important control over forest regeneration and age structure. Minnich (1974) evaluated the role of major fires in initiating secondary succession over large areas of the San Bernardino Mountains where the yellow pine type was adjacent to extensive chaparral areas. As suggested that both the rate and pattern of recovery of forest tree species following five was variable. Specific classification of sites on the basis of environmental parameters has not been used previously to study forest succession.

Materials and Methods

Field Sampling Techniques--

Eighteen permanent plots established in 1972 and 1973 (McBride, 1977) were used in the identification and mapping of facies. The facies were recognized on the basis of species composition, plant height, and cover in the tree, shrub, and herb layers of the forest. Boundaries were established when a change in species composition or cover (more than 25%) occurred. The basic procedure was to walk the entire plot in order to survey the variation in tree, shrub, and herb layers before mapping of the facies. The recognition variable (species composition, plant height, and cover) were recorded for each facies.

Data collected on 45 Jeffrey pine plots of the 83 temporary plots established in 1974 to in investigate forest condition as a function of time since the most recent fire (McBride, 1977) were used in the classification of sites. No additional field data were collected from these plots in 1976-77.

Laboratory Analysis Procedures--

No laboratory analysis procedures were appplied to the facies identified and mapped on the 18 permanent plots.

The field data obtained from the Jeffrey pine plots along with data obtained from published sources (i.e., U.S.G.S. topographic maps) were used to classify sites with a numerical taxonomic clustering technique described by Sneath and Sokal (1973). The following parameters were used for the classification:

1. elevation
2. slope
3 radiation index
4. precipitation
5. soil depth
6. water surplus
7. water-holding index
8. percent clay
9. percent sand
10. soil fraction greater than 2 mm

11. A horizon pH, color and chroma
12. C horizon pH, color and chroma
13. slope aspect
14. percent rock cover
15. percent bare ground
16. position of plot on slope
17. length of slope
18. microrelief (i.e., concave, flat, convex)
19. macrorelief (i.e., level, undulating, rolling, hilly, steep)

Based on the values of each of the above parameters similarity coefficients were derived that compared each site with every other site. (A similarity coefficient is a numerical representation of the overall similarity between two sites). Sites that had the highest average similarity values were grouped together thereby defining clusters containing members (sites) that possessed a high degree of resemblance. These clusters are represented in a tree-like diagram (i.e., phenogram) that is a two-dimensional representation of the interrelation of the study sites (Fig. 6).

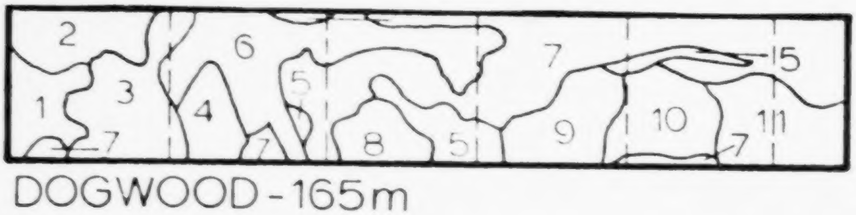
Stepwise discriminant analysis was subsequently applied to determine if any of the sites should be reassigned to other clusters and to evaluate the relative importance of each parameter used to define these clusters.

Results and Discussion

A total of 189 facies were identifed on the 18 permanent plots. Seventeen of these occurred on more than one plot (Table 6). The facies map (Fig. 6) and descriptive data (Table 7) for the Dogwood plot is presented as an example of the maps and data prepared during the study. Maps and data for all 18 permanent plots are available from the Forest Ecology Laboratory, Department of Forestry and Conservation, University of California. The facies maps will provide a basis for relating forest regeneration and plant succession to local variations within the forest types.

The phenogram produced by cluster analysis revealed five fairly distinct clusters (Fig. 7). As one moves along the horizontal axis the first visually apparent cluster includes sites 78 through 50. The membership for the second, third, and fourth clusters are respectively: sites 66 through 55; sites 62 through 59; and sites 71 through 46. The last cluster, sites 60 through 64, can be viewed as a loose assemblage of sites that are least like any of the other sites.

Results of discriminant analysis do not reveal any significant changes in group membership. However, analysis of the territorial map produced by discriminant analysis (Fig. 8), depicting a cluster summary of discriminant scores 1 and 2 for each site, reveals with which parameters the clusters are associated. The horizontal axis represents a moisture complex increasing to the right. Precipitation and water surplus variables provided the greatest influence in this complex. The veritical axis represents an exposure complex decreasing upwaves. The greatest influence in this complex was provided by aspect, radiation index, and macrorelief variables. The map illustrates how the clusters are evaluated along these environmental


2
6
7
15
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8
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9
7
DOGWOOD - 165m

Figure 6. Facies map of Dogwood Plot (see Table 7 for description of facies).

TABLE 6. NUMBER OF FACIES IDENTIFIED ON THE 18 PERMANENT PLOTS USED TO MONITOR AIR POLLUTION INJURY TO FOREST TREES.

Forest Type	Plot	Number of Facies Total	Distinct to Plot	Common to Other Plots
Ponderosa pine	Breezy Point	10	9	1
	U.C. Conference Grounds	4	4	0
	N.W. Camp Paivika	8	5	3
Ponderosa pine-White fir	Camp Angeles	13	8	5
	Camp O-ongo	11	9	2
	Dogwood	11	11	0
	Schneider Creek	15	14	1
	Sky Forest	15	13	2
	Tunnel Two	13	11	2
Ponderosa-Jeffrey pine	Barton Flat	8	8	0
	Green Valley Ck	23	20	3
	Camp Osceola	9	6	3
Jeffrey pine-White fir	Bluff Lake	15	9	6
	Heart Bar	9	9	0
	N.E. Green Valley	11	6	5
	Holcomb Valley	13	6	7
	Deerlick	10	9	1
Jeffrey pine	Sand Canyon	16	15	1

TABLE 7. SPECIES COMPOSITION, TREE HEIGHT, AND COVER OF FACIES ON DOGWOOD PLOT.

	TREE LAYER												
	Upper			Middle			Lower			SHRUB LAYER			GROUND LAYER
FACIES NUMBER	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Species Cover %
1	0			0			0			0			BG 50-75 G 25-50 BF 1-5
2	5-25	50+	IC5-25	25-50	15-25	IC 5-25 BO 5-25	25-50	10-25	WF 1-5 PP 5-25 IC 5-25	0			L 75-100 BF 50-75 G 50-75
3	50-75	50+	PP50-75	50-75	25-50	IC50-75 PP 1-5	0			1-5	>3	BO1-5	L 75-100 BF 1-5
4	1-5	50+	IC 1-5	0			1-5	6-10	IC 1-5 BO 1-5	0			BF75-100 F 1-5 BF 1-5 L 1-5
5	0			0			0			0			L 50-75 BG25-50 BF 5-25 G 1-5
6	0			0			0			0			BG75-100
7	25-5	50+	PP25-50 IC 1-5	50-75	10-25	PP50-75 IC 5-25 WF 1-5	5-25	6-10	PP 5-25 IC 5-25	0			L75-100 BF25-50 G 1-5
8	0			75-100	10-25	BO75-100 PP 5-25 IC 1-5	75-100	6-10	PP75-100 IC 5-25	0			L75-100 BF 1-5
9	75-100	50+	WF 5-25 IC 5-25 SP 5-25	50-75	25-50	PP50-75 PP 1-5 WF 1-5 IC 1-5	25-50	10-25	SP 5-25	0			L75-100 BF 1-5

TABLE 7. CONTINUED

	TREE LAYER									SHRUB LAYER			GROUND LAYER
	Upper			Middle			Lower						
FACIES NUMBER	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Total Cover %	Height	Species Cover %	Species Cover %
10	85-100	50+	PP75-100	0			50-75	10-25	WF25-50 PP 5-25 BO 5-25 SP 5-25 IC 1-5	0			L75-100 BF50-75 G 1-5
11	5-25	50+	PP 5-25	50-75	10-25	PP25-50 BO25-50 SP 5-25 WF 5-25	5-25	6-10	WF 5-25 PP 5-25 SP 5-25	0			L75-100 BF 5-25

*Height in feet

PP = ponderosa pine; BO = black oak; SP = sugar pine; WF = white fir; IC = incense cedar; BG = bare ground; G = grass; BF = bracken fern; L = litter.

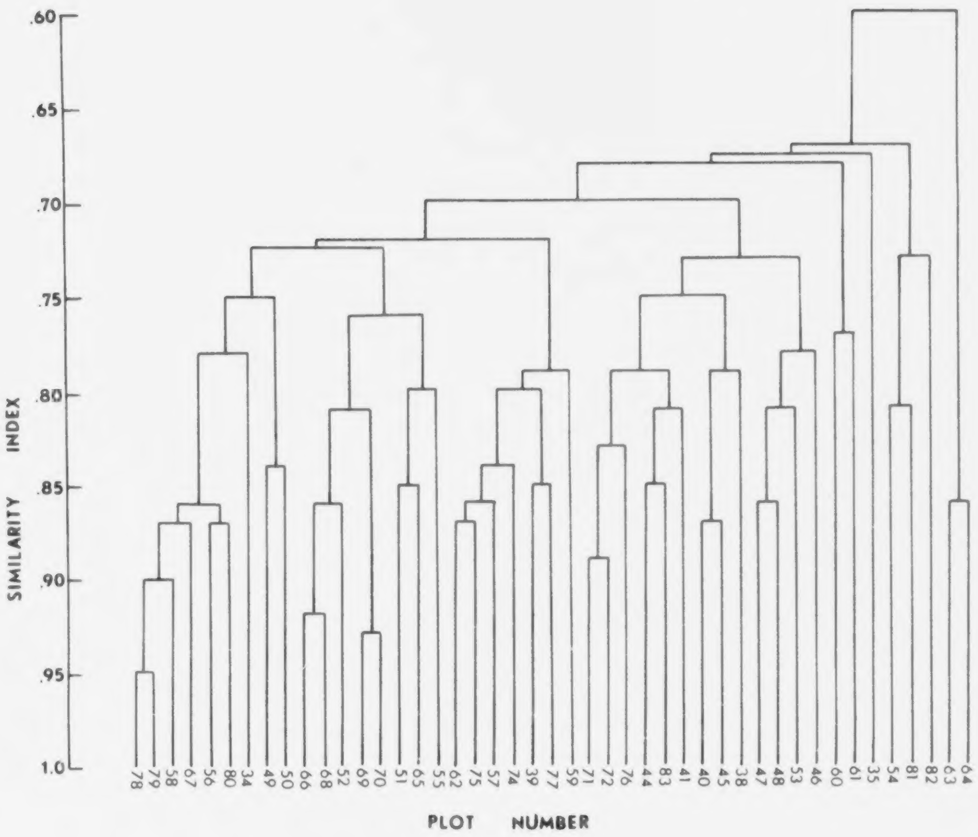

Figure 7. Phenogram illustrating cluster formation.

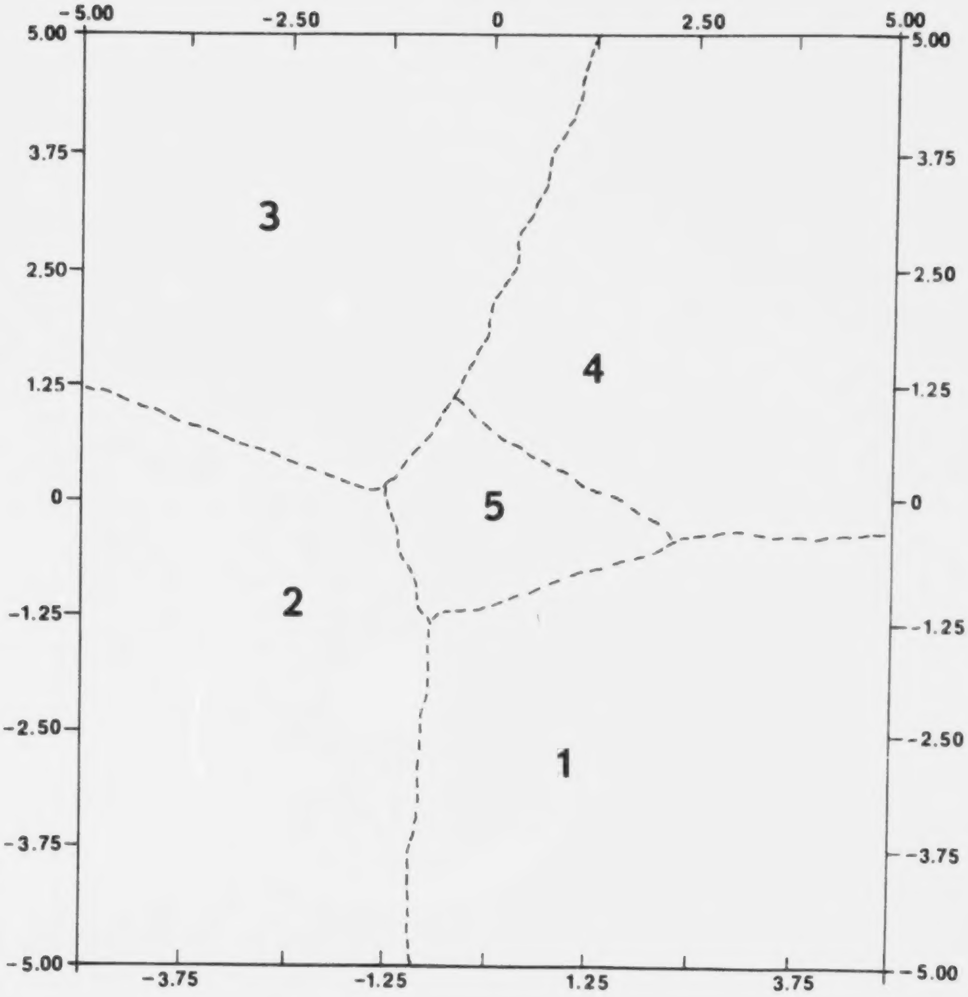

Figure 8. Territorial map of discriminant score 1 (hortizontal) vs. discriminant score 2 (vertical). (Number indicates group centroid of respective clusters.)

complexes. Each of the four clusters are located in a different quadrant indicating that these two environmental complexes successfully distinguish the clusters. The fifth cluster, composed of anomalous sites according to phenogram structure, is located in the center of the map thereby substantiating its status.

Cluster #1 (located in the lower right quandrant of the territorial map) is exposed to an evnironment that is associated with a high moisture complex and a high exposure complex. Cluster #2 is located in the lower right quadrant of the map. This indicates an environment that is associated with a low moisture complex and a high exposure complex. Cluster #3, located in the upper right quadrant, is distinguished by its association with the low moisture and low exposure complexes. Cluster #4, situated in the upper right quadrant, is characterized by a high moisture complex and a low exposure complex.

Since objective techniques were used to group these sites, intra-cluster variation was minimized and each cluster can therefore be considered relatively homogenous. This allows for data collected from these sites to be used to predict plant succession. However, since these clusters are ordinated along the axes of the territorial map and hence exposed to different environments, variations in plant successions between clusters is likely. This assumption will be tested in the next phase of the study.

OXIDANT DOSE - CANOPY RESPONSE SUBSYSTEM

Introduction

A number of different data gathering activities have been undertaken in order to provide the background needed to reach the following objectives:

1) Determine the influences of the May through October oxidant dose and climate on biweekly increases of injury symptoms on the foliage of ponderosa and Jeffrey pines and black oak.

2) Investigate the consecutive year results of tree injury in terms of both the oxidant injury index or score of overstory trees and the height growth of sapling trees.

In objective 1, the data sets that provide hourly temperature and relative humidity information near vegetation plots (FSMET) or on vegetation plots (PLOTMET) were used to compute cumulative daily transpiration for the whole season using a transpiration simulation model (Reed and Waring, 1974). Other data required by the model are designated as STOMRESIST. Operationally they consist of biweekly predawn xylem water potential measurements and associated minimum daily stomatal resistance measurements. A second type of data needed for objective 1 are the hourly ozone or total oxidant averages at stations nearest the vegetation plot (OXIDANT) and on the vegetation plots (PLOTOXID). A third data set required by objective 1 is the biweekly change of injury to needles or leaves of selected trees at each of five vegetation plots (INJBIWK). Injury data is gathered monthly at the remaining vegetation plots.

It will be necessary to couple the output of objective 1 with other data sets described for objective 2 (below) after sufficient testing has established the relationships of transpiration (an integrater of climate), oxidant dose and single season foliage injury.

In objective 2, several effects of multiple years of injury are being investigated concurrently but independent of the output from objective 1. The data sets employed here include the annual evaluation of injury to all plot trees (TREE and TREEMORT) and to saplings nearby (SAPTREE). A retrospective measure of annual height growth of saplings in relation to oxidant injury (SAPGRO) is also included.

A supplemental data set (HMET) includes daily maximum and minimums of temperature, relative humidity and a one time daily wind and precipitation measurement from 9 Forest Service Stations in the San Bernardino Mountains starting in 1976.

Materials and Methods

Equipment and Calibration Methods--

Meteorological--The remote stations for measurement of temperature, relative humidity, winds and net radiation, (FSMET) at Camp Paivika, Sky Forest and Barton Flats and their locations with respect to vegetation plots have been described earlier (Miller, et al. 1977). Hygrothermographs in standard weather instrument enclosures were placed on or near vegetation plots. In May 1976, enough instruments were available to place one from June through October at each location: Camp Angelus (CA), Deer Lick (DL), and Heart Bar (HB). These instruments were within 0.8 to 1.6 km of the vegetation plot of the same name. In May of 1977, instrument shelters with hygrothermographs were placed at the following vegetation plots for the entire summer season: CA,DL, Tunnel 2 (TUN2) and Camp Osceola (CAO). The three remaining hygrothermographs were rotated among the other vegetation plots in the spring of 1977 with measurements for periods ranging from 2-3 weeks.

Air pollution--DASIBI Model 1003AH ozone photometers were maintained at the three FSMET stations (CP, SF and BF) in both 1976 and 1977. These instruments were calibrated at the California Air Resources Board Laboratory in El Monte. Mast Model 724-2 total oxidant analyzers were calibrated by one DASIBI which was reserved for this purpose at the Statewide Air Pollution Research Center (SAPRC). The altitude correction factor for each mountain station was calculated by dividing the larger pressure height (millibars) at the SAPRC by the smaller pressure height at each mountain station. Placement of Mast analysers was coordinated with the schedule described for hygrothermographs on the vegetation plots. Mast analysers and their strip chart recorders had to be battery powered at the vegetation plots. Four, 6 volt, 217 amp-hr batteries were required to operate the Mast analysers when used with a DC to AC inverter. Each set of batteries lasted about 4 days. The strip chart recorders were powered by an internal rechargeable battery pack. The delivery of these Datamart Model D/M #755-M-M recorders was delayed because of a redesign required to lower power drain. Consequently, the on-plot oxidant measurements did not begin until May 1977. The original schedule specified an August 1976 beginning date.

Measurement of Biological Variables--

Data inputs to the transpiration simulation model--The Reed and Waring (1974) transpiration simulator requires both meteorological data, namely hourly temperature and relative humidity, and biweekly measurements of predawn xylem water potential and the associated minimum daily stomatal resistance (r_s). Reed and Waring define xylem water potential in its absolute terms (lbs/in^2) and refer to it as predawn plant moisture stress (PPMS). As soil moisture becomes more depleted during the growing season both PPMS and minimum daily resistance are expected to increase, thus, the daily actual transpiration (Ta) decreases although atmospheric demand or potential transpiration (Tp) may remain large.

Stomatal resistance was related to the only available method of measuring transpiration, namely, infiltraton pressure (IP) in a pressure porometer (Fry and Walker, 1967). A branch of ponderosa pine was cut, mounted on a clamp and exposed to a turbulent air flow at 2000 ft-c and 25 C in the laboratory during a 220 minute period. Initially, and at 10 minute, and later at 30 minute intervals, it was weighed to determine water loss due to transpiration. At similar intervals a needle fasicle was removed to determine the corresponding IP. Resistance (r_s) was calculated at each interval:

$$r_s = \frac{\text{vapor density gradient}}{\text{transpiration}} = \text{sec cm}^{-1}$$

The resistance values ranged from 27 to 115 sec cm^{-1}. The following relationships from Reed and Waring (1974) were used to calculate r_s as a function of IP over the range available:

$$\ln r_s = 1.433 + 0.053\ \text{IP}$$

The key equation necessary to simulate transpiration was the regression between PPMS and minimum daily IP, the equation also from Reed and Waring (1974) was:

$$\text{IP(lb)} = (2.50 \times \text{PPMS [bars]}) - 0.641,\ (r = .53)$$

Daily ppms values were interpolated between the biweekly data points. Actual transpiration (Ta) was then calculated by solving for diffusion conductance (DC) in the equation:

$$\text{DC} = 164.56\ (\text{IP})^{-2.36}$$

Potential transpiration (Tp) was similarly calculated by assuming a maximum value or the largest observed for DC during the entire season at each plot location. Table 8 summarizes the steps described above.

The regression equations above were used for a preliminary run of the transpiration simulator for two plot locations, Camp Angelus and Deer Lick during the May through September period, 1976. In addition, the ratio Ta/Tp was calculated daily as a measure of the relative drought stress at each location and at different times during the season. This ratio is proposed as one criterion for testing the quantitative relationship between plant moisture status throughout the season and ozone dose response.

Concurrently, an effort has been under way to improve the accuracy of

TABLE 8. MAJOR INPUTS, INTERNAL OPERATIONS AND OUTPUTS OF THE TRANSPIRATION SIMULATOR

Variables	Source or Product Dataset
Inputs	
Mean Hourly Temperature (^{o}C)	FSMET and
Mean Hourly Relative Humidity (%)	PLOTMET
Predawn Plant Moisture Stress (PPMS) (interpolated between biweekly determinations)	STOMRESIST
Minimum Daily Stomatal Resistance (r_s) (as a function of PPMS)	
Internally Generated Parameters	
Vapor Pressure Deficit (VPD) (night and day)	
Diffusion Conductance (DC) = $1/r_s$	
Outputs	
Daily and Cumulative:	TRANSPR
Actual (Predicted) Transpiraton (Ta)	
Potential Transpiration (Tp)	
Ratio: Ta/Tp	

the regression between minimum daily stomatal resistance r_s and PPMS without relying on the pressure porometer so that r_s can be substituted for IP directly. A diffusion porometer fabricated and calibrated by the Lawrence Livermore Laboratory (Bingham and Coyne, 1977) was used to obtain some mimimum r_s data. Unfortunately the unusual amount of summer rain during 1976 and 1977 prevented us from obtaining sufficient data points at moderate and high levels of PPMS. STOMRESIST is designated as the data file for PPMS and r_s. Plot locations where PPMS and r_s data have been obtained include DWA, TUN2, DL, CA, CAO and HB. Trees were selected as close as possible to the soil moisture sensor column in each plot or immediately outside the plot. Two to three trees were selected at each plot; one represented an overstory tree larger than 30 cm dbh and the second an understory tree less than 30 cm dbh. Trees with moderate to severe oxidant injury were not selected at this time because the limited amount of time available during the predawn period (3 to 6 am) made it impossible to observe all injury classes especially because travel time between the 3 plots was a big limiting factor. The selection of healthy or slightly injured trees was done to provide the initial data because these trees are expected to have the greatest survivorship and thus a requirement for predictive information. The concurrent studies being done by Coyne and Bingham (1978) include three injury categories, e.g. very slight, slight to moderate and moderate to severe at one ponderosa pine stand near Crestline. Their data will be helpful to us when it is reported.

Estimates of injury to foliage at intervals during the season--During the 1976 and 1977 summer seasons five plots were visited every two weeks to observe the amount of visible injury to selected ponderosa or Jeffrey pines, white fir and black oak. A minimum of two trees of each species in each of six oxidant injury score categories were selected throughout for continuing observation. The ponderosa and Jeffrey pine categories included 0-8 (very severe), 9-14 (severe), 15-21 (moderate), 22-28 (slight), 29-35 (very slight) and 36 and higher (no visible injury). White fir and black oak were also divided into six catagories. Usually about three categories were present on each plot as determined from the oxidant injury scores from 1975. Preselected trees were first inspected so that disease or insect problems which may interfere with the development of oxidant injury symptoms could be avoided. Three branches on each selected tree species were tagged except for white fir which had one tagged branch. On the ponderosa and Jeffrey pines, eight needle fasicles were labeled in each successively younger needle whorl starting with the 1975 needle whorl. Each of the eight needle fasicles were enclosed in a loop made with one length of colored, vinyl covered copper telephone wire. Table 9 summarizes the kinds of data gathered either biweekly or monthly in 1976 and 1977 from mid-June through the end of September.

On ponderosa and Jeffrey pines a "3 M" device was used to measure total needle length affected by chlorotic mottle. This "metric mottle measurer" was a transparent plastic tube about 30 cm long and 0.5 cm, i.d. It was painted black on one third of the external surface for the full length, and etched every 0.5 cm. This device which was developed by Tom Quick was proven to be useful. When the needle fasicle was

TABLE 9. DESCRIPTION OF INFORMATION COLLECTED TO DESCRIBE THE WITHIN SEASON DEVELOPMENT OF OXIDANT INJURY SYMPTOMS ON PONDEROSA PINE (PP), JEFFREY PINE (JP), WHITE FIR (WF), BLACK OAK (BO).

Species	Type of Data	Frequency
PP and PJ	For each labeled branch, and whole needle whorls, starting with 1975: --Total number of needles per whorl	June and September
	For the same labeled branch and for 8 labeled or "wired" needle fasicles in each whorl since 1975: --Number of the 8 needles remaining. --Total length of each of the 8 needles (cm). --Portion of the total length with identifiable symptoms (cm). --Intensity of injury symptoms on each needle (Table 10).	Biweekly or Monthly
WF	For the single labeled branch: --Number of annual needle whorls retained (first observation in 1975). --Intensity of symptoms on needles or each whorl (Table 10).	Biweekly or Monthly
BO	For each labeled branch: --Intensity of symptoms on representative leaves (Table 10).	Biweekly or Monthly

slipped into the tube for measurement (down to the top of the fasicle wrap) the needle was isolated momentarily against a dark background which aided the measurement of chlorotic mottle. In Table 10 the different subjective categories are described for characterizing symptom intensity. These categories are more refined than those used in the end-of-season oxidant injury score. In that case 0 = severe chlorotic mottle and advanced necrosis, 2 = any discernable chlorotic mottle and 4 = an uninjured green needle. In the refined version, the greater injury is assigned a larger number so that injury resposes would have a positive slope. Scores of 7, 6, and 5 for the pines, white fir and black oak respectively signaled needle or leaf abscision.

Records of vertical growth on ponderosa and Jeffrey pine saplings 1967 to 1976--In September of 1976, the internodal growth of saplings was measured with the aid of a fruit picker's ladder (SAPGRO). Internodes preceding 1967 were also measured when they could be confidently identfied. The oxidant injury scores of each of the 50 ponderosa or Jeffrey pines in the plots was last determined in 1975 (SAPTREE). These plots were located within or nearby the following major vegetation plots: SF, CP, DWA, BL, BP, TUN2, CA, HV, CAO and HB.

Annual measurement of oxidant injury to trees larger than 10 cm dbh at major vegetaton plots--The procedure has been described in earlier reports. Comparisons between years is done by using the paired t test to compare each tree with itself from one year to the next.

Summary of data gathering activities--Table 11 shows when and where eight data sets are obtained. Daily and cumulative daily transpiration (TRANSPR) is calculated from FSMET, PLOTMET and STOMRESIST but it is included in the table thus bringing the total number of data sets to nine. The oxidant injury scores for saplings (SAPTREE) is not included in the table because this information has not been obtained on a regular annual schedule as originally planned. SAPTREE and TREE must be obtained during the September to November period each year; TREE has been given first priority. Good weather and qualified manpower were available in 1973 and 1975 to allow SAPTREE to be obtained. It must be done in 1978 without fail.

Results and Discussion

Meteorological Effects on Seasonal Oxidant Dose--

One method of summarizing the influence of seasonal climate on oxidant dose was introduced in the last progress report (Miller, et al. 1977), namely, the frequency of five classes of meteorological patterns in southern California (McCutchan and Schroedor, 1973) and the oxidant dose related to single and consecutive days of each type. The following are brief definition of these types:

1) Hot dry continental air all day (Santa Ana)

TABLE 10. SUBJECTIVE CATEGORIES FOR DESCRIPTION OF OXIDANT INJURY SYMPTOMS ON PONDEROSA (PP), JEFFREY PINE (JP), WHITE FIR (WF), AND BLACK OAK (BO).

Species	Numeric Category	Description of Leaf Symptoms
PP and JP	0	-Completely grass green (PP) Completely gray green (JP)
	1	-Slight chlorosis or very slight chlorotic mottle
	2	-Distinct, bright yellow chlorotic mottle
	3	-More intense chlorotic mottle and some uniform chlorosis
	4	-Intense mottle with necrosis appearing at needle tips, not exceeding the distal 1/3 of the needle
	5	-Intense mottle with necrosis occupying the distal 2/3 of the needle
	6	-Entire needle necrotic, appearing dry and brown
	7	-Needle abscission
WF	0	-Completely green or gray-green
	1	-Light green and/or chlorotic mottle barely distinguishable on the sides (thinnest part of the elliptical cross section) or at the needle tip

(continued on next page)

TABLE 10. CONTINUED

Species	Numeric Category	Description of Leaf Symptoms
WF continued	2	-Mottle more definite (bright yellow) sometimes uniformly chlorotic
	3	-Intense mottle and the tip 1/3 of the needle is necrotic
	4	-Uniform yellow and at least 2/3 of the needle is necrotic
	5	-Needle is entirely necrotic
	6	-Needle abscission
BO	0	-Leaf completely green
	1	-First evidence of interveinal chlorosis, chlorotic mottle or necrotic lesions mainly on upper surfaces
	2	-Moderate levels of interveinal chlorosis, chlorotic mottle and/or necrosis mainly on upper surface
	3	-More severe than 2 with necrosis extending to the lower leaf surface
	4	-Whole leaf is necrotic, both surfaces

TABLE 11. DESCRIPTION OF DATA TYPES AND FREQUENCY OF DATA COLLECTION FOR EACH TYPE AT MAJOR VEGETATION PLOTS IN 1976 AND EARLY 1977.

		Acronyms for data types							
Plot Name	Species	FSMET/ OXIDANT	PLOTMET	PLOTOX	STOM-RESIST	INJ-BIWK	TRANSPR	SAPGRO	TREE
COO	p,f,o	-----	-----	-----	-----	plot/mo	-----	-----	ann.
BP	p,f,o	-----	-----	-----	-----	plot/mo	-----	ann.	ann.
CP	p,o	hourly	-----	-----	-----	plot/mo	-----	ann.	ann.
SF	p,f,o	hourly	-----	-----	-----	plot/mo	-----	ann.	ann.
DWA	p,f,o	-----	-----	-----	on/near plot/ biwk	plot-sap/ biwk	daily/ cum.	ann.	ann.
UCC	p,o	-----	-----	-----	-----	plot/mo	-----	-----	ann.
TUN2	p,f,o	-----	hourly	hourly	on/near plot/ biwk	plot-sap/ biwk	daily/ cum.	ann.	ann.
DL	j,f,o	-----	hourly	hourly	on/near plot/ biwk	plot/ biwk	daily/ cum.	-----	ann.
GVC	p,j,f,o	-----	-----	-----	-----	plot/mo	-----	-----	ann.
BL	j,f	-----	-----	-----	-----	plot/mo	-----	-----	ann.
NEGV	j,f	-----	-----	-----	-----	plot/mo	-----	-----	ann.
SC	p,f,o	-----	-----	-----	-----	plot/mo	-----	-----	ann.
HV	j,f,o	-----	-----	-----	-----	plot/mo	-----	ann.	ann.
SCR	p,f,o	-----	-----	-----	-----	plot/mo	-----	-----	ann.

(continued on next page)

TABLE 11. CONTINUED

		Acronyms for data types							
Plot Name	Species	FSMET/ OXIDANT	PLOTMET	PLOTOX	STOM-RESIST	INJ-BIWK	TRANSPR	SAPGRO	TREE
CA	p,f,o	hourly	-----	-----	near plot/ biwk	plot-sap/ biwk	daily/ cum	ann.	ann.
BF	p,j,o	hourly	-----	-----	-----	plot/mo	-----	-----	ann.
CAO	j,f,o	-----	hourly	hourly	on/near plot/ biwk	plot-sap biwk	daily/ cum	ann.	ann.
HB	j,f	-----	-----	-----	near plot biwk	plot/mo	daily/	ann.	ann.

Species present:
p - ponderosa pine
j - Jeffrey pine
f - white fir
o - black oak

Comprised of biweekly predawn plant moisture stress (PPMS) and associated stomatal resistance (r_s) measurements made on 2 ponderosa or Jeffrey pines

10 cm dbh; located in plots or immediately outside plots within 30 m of the soil moisture sensor column.

Needle injury data taken from selected plot trees of all species ≥ 10 cm dbh and from sapling ponderosa and Jeffrey pines < 10 cm dbh at 4 plots at monthly (mo) or biweekly (biwk) intervals.

Sapling height growth (SAPGRO) and the oxidant injury score (TREE) are determined annually (ann.).

2) Relatively dry forenoon, modified marine air in the afternoon; very hot (heat wave)

3) Moist, modified marine air, hot in the afternoon

4) Moist, modified marine air, warm in the afternoon

5) Cool moist, deep marine air throughout the day.

It was concluded that consecutive occurrences of Class 3 days were the most numerous in 1974 and resulted in the highest daily dose of oxidant. Consecutive Class 4 days followed very closely behind in frequency and the size of the resultant oxidant dose. The primary reason for the higher dose in 1974 (Fig. 9) was the larger number of Class 3 followed by 3 transitional combinations (Table 12). The lower seasonal oxidant dose in 1976 (Fig. 9) was evidently associated with a higher frequency of transitional combinations which induce lower daily oxidant doses, namely, 5-5, 4-5, 5-4 and 1-1 (Table 12). In general, the 1976 season was cooler and marked by greater than usual rainfall particularly on September 11, when a tropical storm persisted over southern California. The cumulative oxidant dose in June 1976 was particularly lower than the June of 1974 and 1975 (Fig. 9). There were 13 Class 5 (cool, moist) days in June 1976 compared to 7 in 1975 and 4 in 1974. These results give a general view of the trends in seasonal oxidant dose in relation to climate. The results in the following section will attempt to show the coupling between seasonal climate, oxidant dose and tree injury response.

Daily and Cumulative Transpiration--

Daily and cumulative transpiration at Camp Angeles and Deer Lick, 1976--The transpiration simulator provides both actual and potential transpiration on a daily basis. Potential transpiration is a measure of atmospheric demand. The ratio of actual to potential transpiration (Ta/Tp) is a useful index of the relative drought stress at different locations as well as throughout the season at the same location. Several observations can be listed: First, the time series in Figures 10 and 11 suggest that higher cumulative weekly oxidant doses coincided with periods of higher potential transpiration throughout the season at both Deer Lick and Camp Angeles. The scatter diagram (Figure 12) relating daily oxidant dose to daily potential transpiration at Camp Angeles in 1976 further suggests a relationship between transpiration demand (Tp) and concurrent oxidant dose. Second, the ratio Ta/Tp at both DL and CA responded by becoming lower following continuous periods of moderate to high potential transpiration and higher following significant rain on Julian dates 211 and 254. Third, it is possible that a high oxidant dose occurring during a period of high Ta/Tp (higher actual transpiration) would be more injurious than in the opposite circumstance, namely, a low Ta/Tp. The reason may be that ozone flux to needle tissue may be larger during periods of higher actual transpiration (high values of Ta/Tp). For example, in Figure 10 ozone flux could be expected to be larger in early July than in late August. In Figure 11, the first small peak of Ta/Tp coincides with a short period of high oxidant in mid-June and the lowest value of Ta/Tp in late august also coincides with

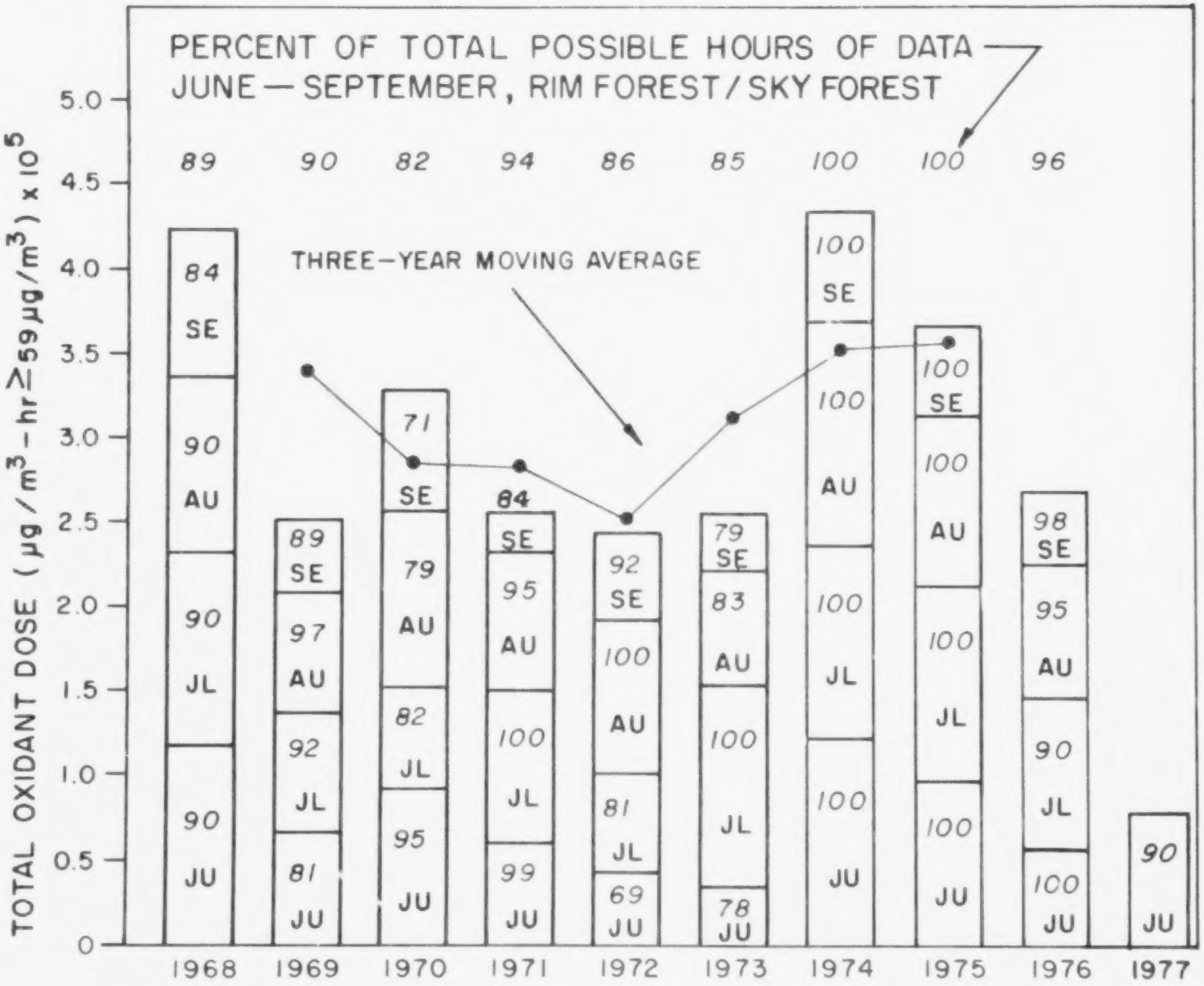

Figure 9. Trend of seasonal oxidant dose at a representative San Bernardino mountain station from 1968-1977.

TABLE 12. FREQUENCY OF DIFFERENT TRANSITIONAL COMBINATIONS OF FIVE CLASSES OF SPRING AND SUMMER DAYS[+]

Transitional Combinations		n	1974 Percentage	n	1975 Percentage	n	1976 Percentage
4	4[*]	32	18.7	54	32.0	37	22.0
3	3[**]	53	31.0	17	10.1	23	13.7
5	5	22	12.9	22	13.1	34	20.2
2	2	8	4.7	16	9.5	8	4.8
3	4	11	6.4	8	4.8	8	4.8
4	5	9	5.3	9	5.4	16	9.5
4	3	8	4.7	8	4.8	7	4.2
5	4	9	5.3	7	4.2	13	7.7
1	1	6	3.5	9	5.4	12	7.1
2	3	6	3.5	6	3.6	4	2.4
3	2	4	2.3	6	3.6	3	1.8
2	4	1	0.6	4	2.4	3	1.8
4	2	2	1.2	2	1.2	0	0

[+] Day classifications were obtained from Morris H. McCutchan, Project Leader, Fire Meteorology Project, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S.D.A., Riverside, CA.

[*] The 12 remaining possible combinations occurred only 3 percent of the time or less and are omitted.

[**] The dose (ppm-hrs) on the second day of the most common transitional combinations is indicative of the pollution potential, for example, the combined data from 1974 and 1975 (Miller, et al., 1977) showed the following doses associated with these combinations: 3-3 = 2.09, 3-4 = 1.90, 2-2 = 1.88, 4-4 = 1.76, 5-5 = 0.78 and 1-1 = 0.38 ppm-hr.

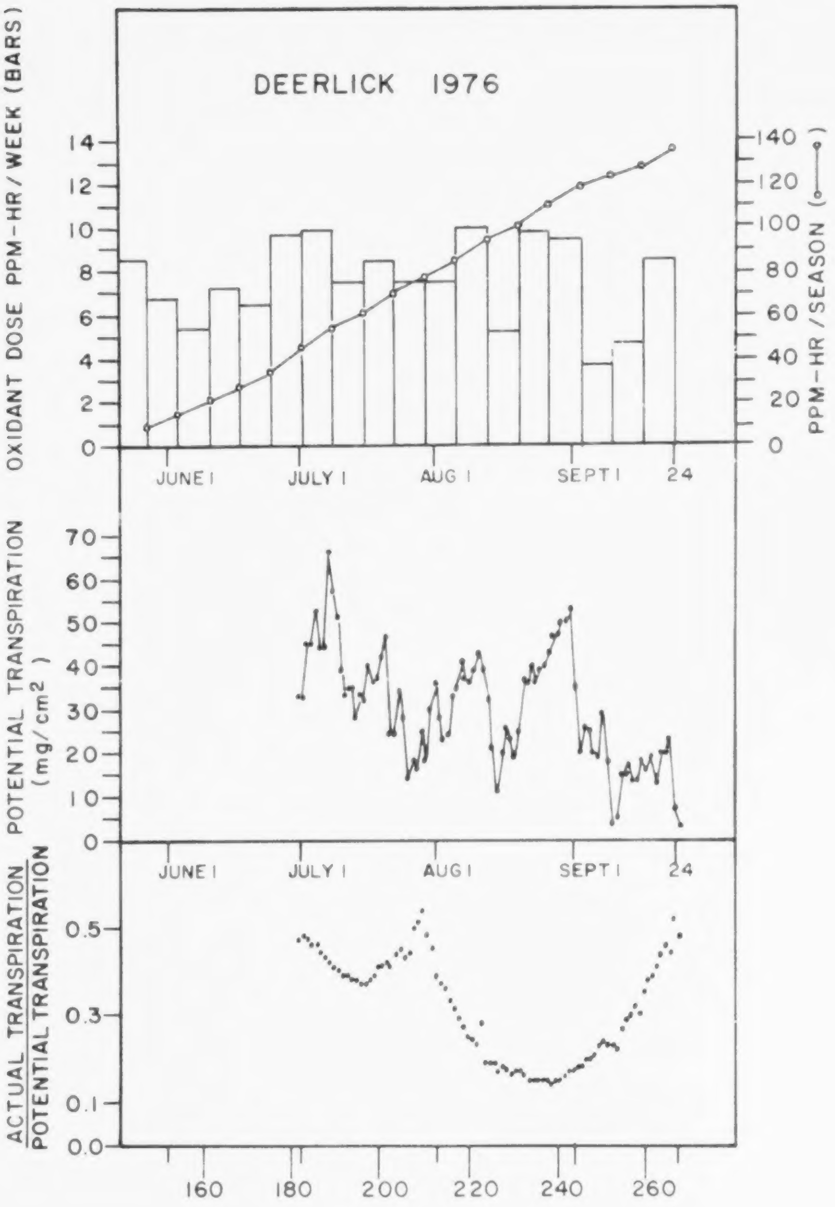

Figure 10. Seasonal pattern of potential transpiration, ratio of actual over potential transpiration and cumulative oxidant dose at Deer Lick, 1976.

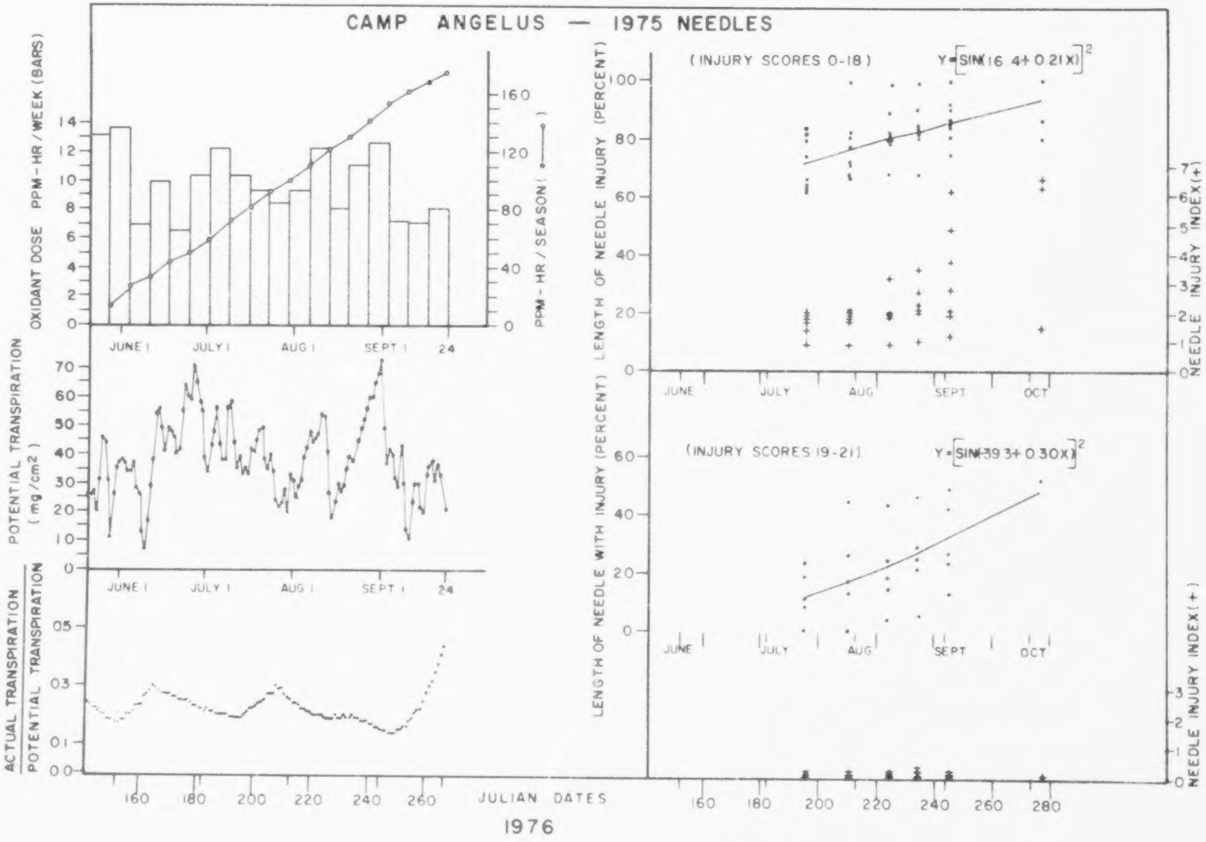

Figure 11. Comparison of injury to the 1975 needle whorl with potential transpiration and the ratio of actual over potential transpiration at Camp Angelus in 1976.

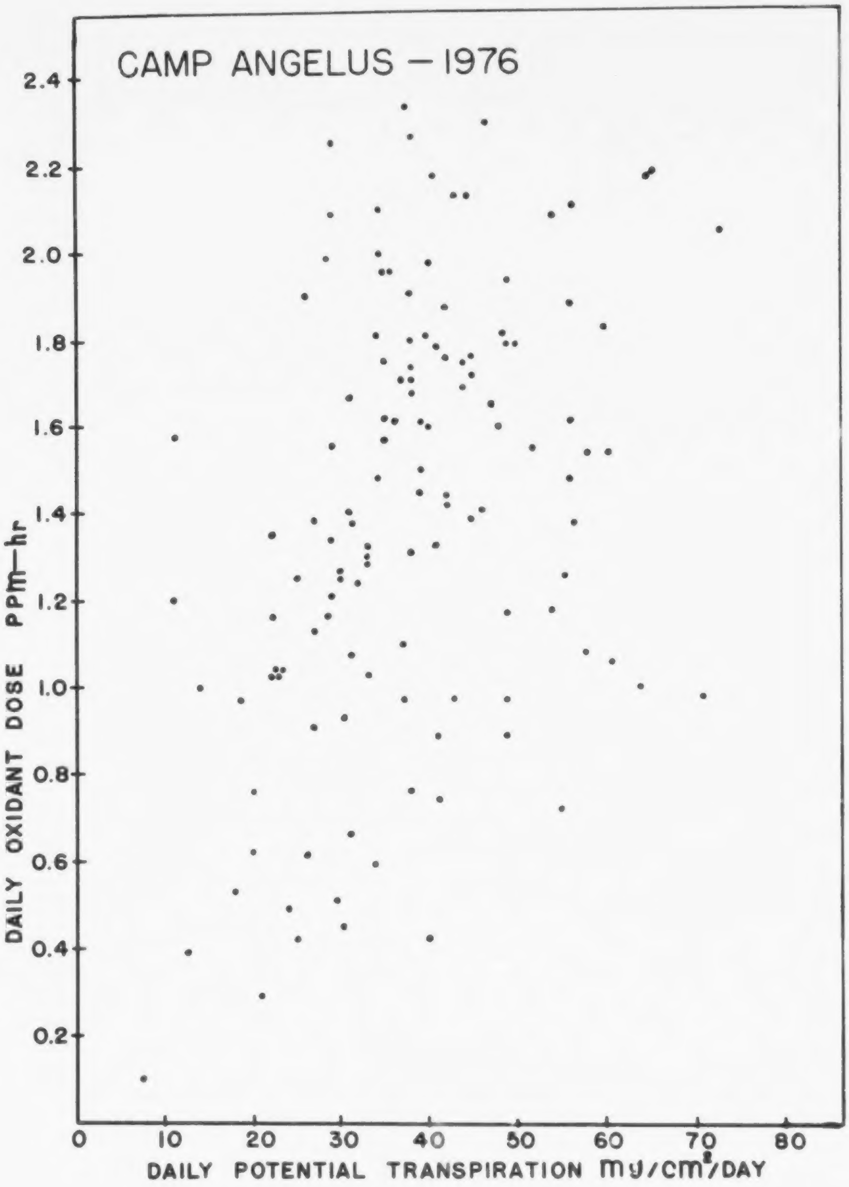

Figure 12. Relationship of daily potential transpiration and daily oxidant dose at Camp Angelus during May through September, 1976.

a high dose period. A scatter diagram (not shown) relating the weekly oxidant dose (ppm-hr) to the average of the daily values of Ta/Tp for the same week for 18 weeks at Camp Angelus in 1976 did not suggest a relationship between two variables over a range of 0.14 to 0.35 for Ta/Tp. An adjusted ozone dose for the whole season might be calculated by multiplying daily Ta/Tp times the daily dose but it appears that a wider range for the Ta/Tp variable will be needed to more carefully examine the modifying effect that it may have on the development of needle symptoms. MuKammal (1965) found that by multiplying the daylight oxidant dosage by the coefficient of evaporation he could reduce the scatter of data points describing dose-injury response of tobacco.

At this time, we have calculated seasonal transpiration at only two of the six plots where data is available (CA, CAO, HB, TUN2, DWA and DL). It will be helpful to find the seasonal ranges of Ta/Tp at other plots which are expected to be both drier and more moist than CA and DL. Since three of the plots are dominated by ponderosa pine (CA, TUN2 and DWA) and the remaining three have Jeffrey pine it may be possible to evaluate differences in transpirational behavior that may be related to species. When the data from 1977 is considered in addition, we have processed only one sixth of the available data. An improvement in the precision of the regression formula relating predawn xylem water potential and minimum daily stomatal resistance will be incorporated as soon as possible.

The relationship between soil moisture content and transpiration (Ta) can be determined, as proposed in the systems modeling plan by Kickert in Miller, et al (1977), in cooperation with Rod Arkley using the relationship in the model described by Thompson and Hinckly (1977).

Development of ozone injury to foliage of ponderosa and Jeffrey pines, 1976 and 1977--The preliminary results showing the relationships between Tp, Ta/Tp, and cumulative oxidant dose (weekly and seasonally) (and development of oxidant injury symptoms to ponderosa pine needles) is shown in both Figure 11 and 13 for Camp Angelus in 1976. The increase in the percentage of needle length exhibiting injury of any intensity (Table 11) and the increase of injury severity on the same needles versus Julian date show differing responses depending on the oxidant injury scores of ponderosa pines at Camp Angeles. Needle injury was barely detectable on Jeffrey pines at Deer Lick in 1976; no data are presented in graphic form. A regression line was calculated for "injured length" at CA because it is derived from a continuous metric scale, but not for the needle injury index because it is the product of a subjective judgement for which scale units cannot be assumed to be of uniform size at all points of the scale. It is evident however, that injury intensity increased moderately for the more sensitive group of trees (0-18) compared to the less sensitive group (19-21) The 1975 needles began the 1976 season with some injury accumulated in 1975. The new needles produced in 1976 (not shown in Figure 11) did not show injury until the September observation and then about 12 percent of the needle length exhibited injury. The increase of injury to the 1975 needles in 1976 (1 year old) and 1977 (2 years old) is shown in Figure 13. From 1976 to 1977, the percent of the needle length with injury (chlorotic mottle) of 1975 needles increased with very slight recovery over the 1976-77

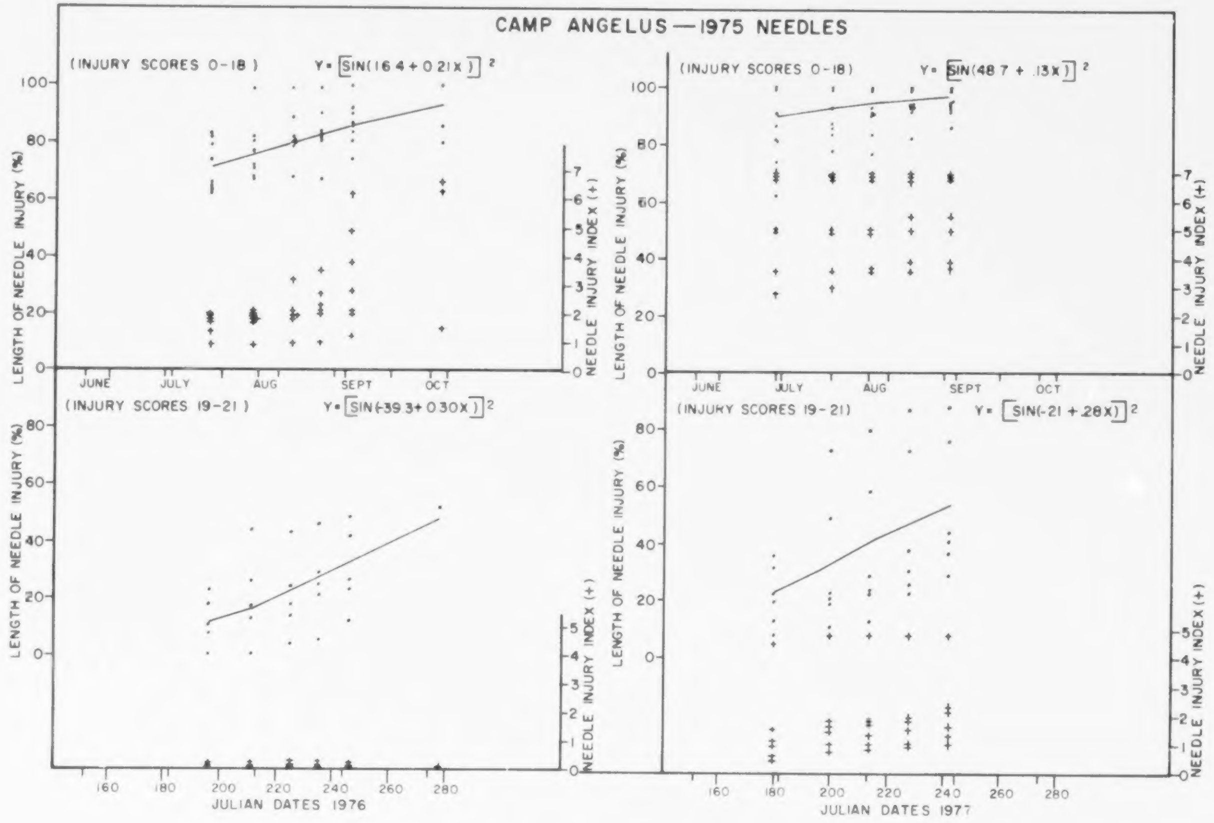

Figure 13. Changes of 1975 needle whorl injury in 1976 and 1977 at Camp Angelus.

winter for trees in the oxidant sensitive (0-18) score range whereas the less sensitive group of trees (19-21) may have recovered slightly over winter. The regression lines for needle length with injury show increases of injury in 1977; symptom intensity (needle injury index) increased similarly. Needle abscision was not observed until more than 90 percent of the needle length showed injury on trees in the sensitive group (0-18).

As illustrated in Figure 13, the fate of 1975 needles can be followed year after year. The same is true for 1976 and 1977 needles. Other information that can be derived from the INJBIWK data set includes the rate of needle elongation of the new needles each year; total length of needles; the longevity of needles; and the annual change in green or mottled needle surface area relative to tree sensitivity.

The biweekly changes in injury to white fir are not reported because the lower injury response compared to ponderosa and Jeffrey pine has resulted in little change of needle condition or needle retention over the single 1976 observation year. Black oak injury data and the monthly observations of injury to all four species has been keypunched and given preliminary processing. These results will be reported in conjunction with the 1977 injury data.

Progress in development of a single season ozone dose, foliage injury model--Transpiration, oxidant dose and foliage injury data sets for CA and DL have been completed for 1976 and 1977. A preliminary analysis of the relationships between injury to 1975 needles from the moderate injury (19-21 injury score) group of ponderosa pines at Camp Angeles in 1976 (Figure 13, lower left) and the cumulative oxidant dose alone or the cumulative dose multiplied by the ratio of actual to potential transpiration (Ta/Tp) is shown in Figure 14. The biweekly mean of daily Ta/Tp was multiplied times the dose increment for the same period. The effects of the multiplication were to "weight" each biweekly dose increment and to change the total of the cumulative seasonal dose from 160 to 38 ppm-hr. It is evident from the small range of values for Ta/Tp at Camp Angeles in 1976 (Figure 11, lower left) that the ratio was nearly a constant until the very end of the season (Julian Date 250 to 265); it did not "weight" the dose in any significant way. In this example, either dose injury relationship in Figure 14 would be acceptable. The analyses that will be done with data from other plots may test the utility of the transpiration ratio in describing dose if the range of the ratio is larger. The cumulative dose documented on a daily or biweekly basis seems to be an appropriate unit for expressing dose. The geometric mean for biweekly increments of the whole season does not seem to provide a scale with fine enough resolution but it should be tested.

Existing dose response models (Larsen and Heck, 1976) deal with single concentrations for periods not exceeding 8 hr. In chronic exposures, the dose pattern is usually characterized by a series of high concentration episodes occurring at random intervals and linked by consecutive days with lower or moderate concentrations of oxidant; this generates new questions. What sequences or seasonal patterns of high concentration episodes are most injurious? It is assumed that periods of high actual transpiration would contribute to more rapid injury development because of a larger ozone flux

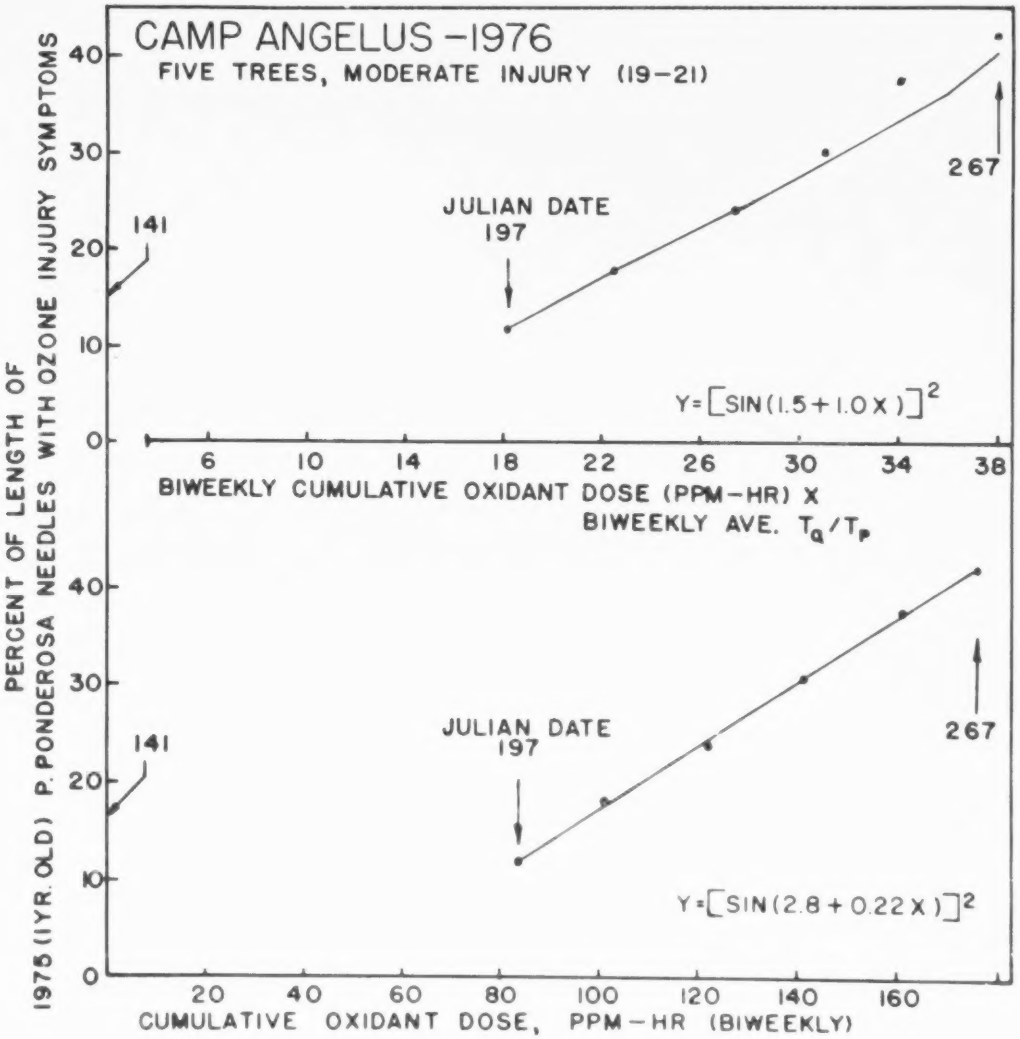

Figure 14. Changes in the percent of the total needle length of selected ponderosa pines with chlorotic mottle in relation to two measures of cumulative oxidant dose.

to foliage, but is there a point on the lower end of the available soil moisture curve where the lowered transpiration rate (that may limit ozone flux to needles) increases to drought stress proportions? Drought stress would mainly accelerate abscision of the needles already injured by ozone.

The worst case conditions that may cause the greatest injury in a single season are hypothesized as follows: Abundant soil moisture at the beginning of the season followed by hot weather in June and July which would result in numerous closely spaced episodes of high ozone concentrations, and a continuing high potential transpiration throughout August and September. The Ta/Tp ratio would decrease gradually until late July and oscillate only slightly at a low level for the remainder of the summer season. The drought stress induced in August and September may decrease carbon fixation in the remaining needles in addition to accelerating needle abscision.

Some very important results have been obtained by Coyne and Bingham (1978) that focus on changes in stomatal behavior of pole-size ponderosa pines in the San Bernardino mountain near Camp Paivika and of container-grown trees under greenhouse conditions. The most important variables measured in the study included: predawn and daylight xylem water potential and stomatal conductance in relation to amount of chronic injury to ponderosa pines under field conditions. Some of these results run counter to the hypothesis that has been developed in our report, namely, that injury during a given season is mediated mainly by stomatal resistance, i.e., high predawn xylem water potential would result in a lower stomatal resistance (increased conductance), hence increased pollutant flux to needle tissue. Their data shows that as needles on individual trees showing increasing amounts of chronic injury (lower oxidant injury scores) become more injured as the summer season progresses, their stomatal resistance also increases. This event is accompanied by drastic declines in apparent photosynthesis. In summary: 1) Increased needle injury is associated with increased stomatal conductance and decreased stomatal resistance and decreased water loss; 2) The relationship between xylem water potential (container grown trees) and stomatal conductance is basically sigmoid for both uninjured and ozone-injured trees but as xylem water potential increases over a arange from 0 to 25 bars the steep part of the curve is between -10 and -14 for uninjured trees and -14 to -16 for ozone injured trees; 3) Increased stomatal resistance would decrease pollutant flux to needles. 4) Because other internal variables may also influence stomatal behavior, e.g. higher levels of abscissic acid, "the influence of water stress can more readily be described as an operational limit beyond which stomatal aperture can not increase."

The small amount of data that we have described in this report does not dispute the results of studies done by Coyne and Bingham (1978) and we will hasten to complete the analysis of the remaining data so that our research can be directed towards the most crucial questions pertaining to the description of the chronic ozone dose-injury relationship for ponderosa and Jeffrey pine.

Another variable that may have an important influence on injury development is needle phenology. Earlier studies with container grown ponderosa pines fumigated with ozone suggested that the injury from the same concentration, 0.45 ppm, increased as the summer progressed. A large number of trees were held in a filtered air greenhouse and at 4 week intervals (during 3 summers) a new group of 40 trees was fumigated. Smaller doses were required to cause equivalent injury to current and one-year-old needles as the summer season advanced (mid-June to mid-September). These trees were not water stressed (Miller, 1973). If this observation holds true under field conditions, it would suggest that higher dose episodes in late August and September may result in increased injury under the regulation of unknown and unspecified controls at the physiological level; these controls may be independent of stomatal behavior.

Annual Shoot Growth of Ponderosa and Jeffrey Pine Saplings From 1967-1976--

Internode lengths of terminal shoots and oxidant injury score--The link that may be the most practical in coupling oxidant injury to growth of smaller trees is foliage surface area retained. For example, Kozlowski and Winget (1964) showed by removal of various proportions of needles from *Pinus resinosa* that the old (all except the current year whorl) needles provided the food reserve that accounted for four-fifths or more of all shoot growth. The combined reserves in the branches, main stem and roots accounted for less than 15 percent of shoot growth.

The oxidant injury score used for both sapling and sawtimber sized trees is comprised of the number of needle whorls retained on the main stem and a mid-crown branch for saplings and for the upper and lower crown in larger trees. It is presently a crude index of foliage retained but may be expanded to foliage surface area estimates in combination with other parameters. In Figure 15, the preliminary linear regression lines show the average of the annual shoot growth (internode lengths) between 1967 and 1976. Most of this period was characterized by high seasonal oxidant doses (Fig. 9). The best correlation between injury score determined in 1975 and growth was at those plot locations experiencing the highest doses namely CP, SF and BP. The maximum value for each line may be an approximate measure of the site quality where the 25 to 40 trees were growing. The ponderosa pine plots had shown greater height growth than the Jeffrey pine plots (HV, CAO, HB and BL). This difference is believed to be associated with lower rainfall and lower mean temperatures at the Jeffrey pine plots compared to the ponderosa pine plots. The regression lines in Figure 15 should be regarded as an approximation because the independent variable (oxidant injury score) is not based on continuous variable data but is a composite of discontinuous variables, ranked variables and attributes. One of the most important problems that we face is to find acceptable ways to use selected variables in the index for purposes of statistical analyses.

At the ponderosa pine plots experiencing the highest doses of oxidant (Miller, et al. 1977) the sample populations could be divided into several injury score groups which also exhibited growth differences commensurate with their injury category (Fig. 16). The year to year variability in growth of all injury score groups is definitely associated with rainfall amount but the differences between groups is mostly attributable to seasonal oxidant

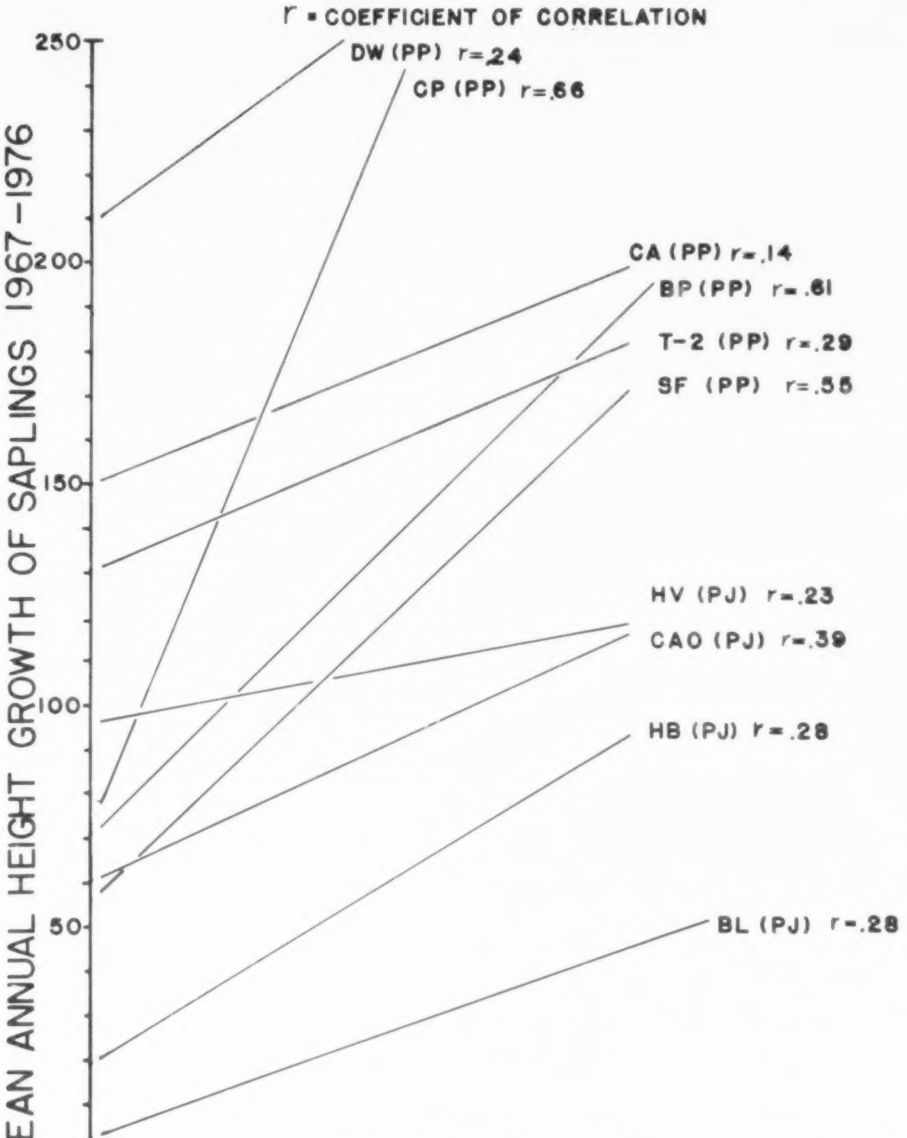

Figure 15. Average height growth of ponderosa and Jeffrey pine saplings at plots experiencing different levels of chronic oxidant injury.

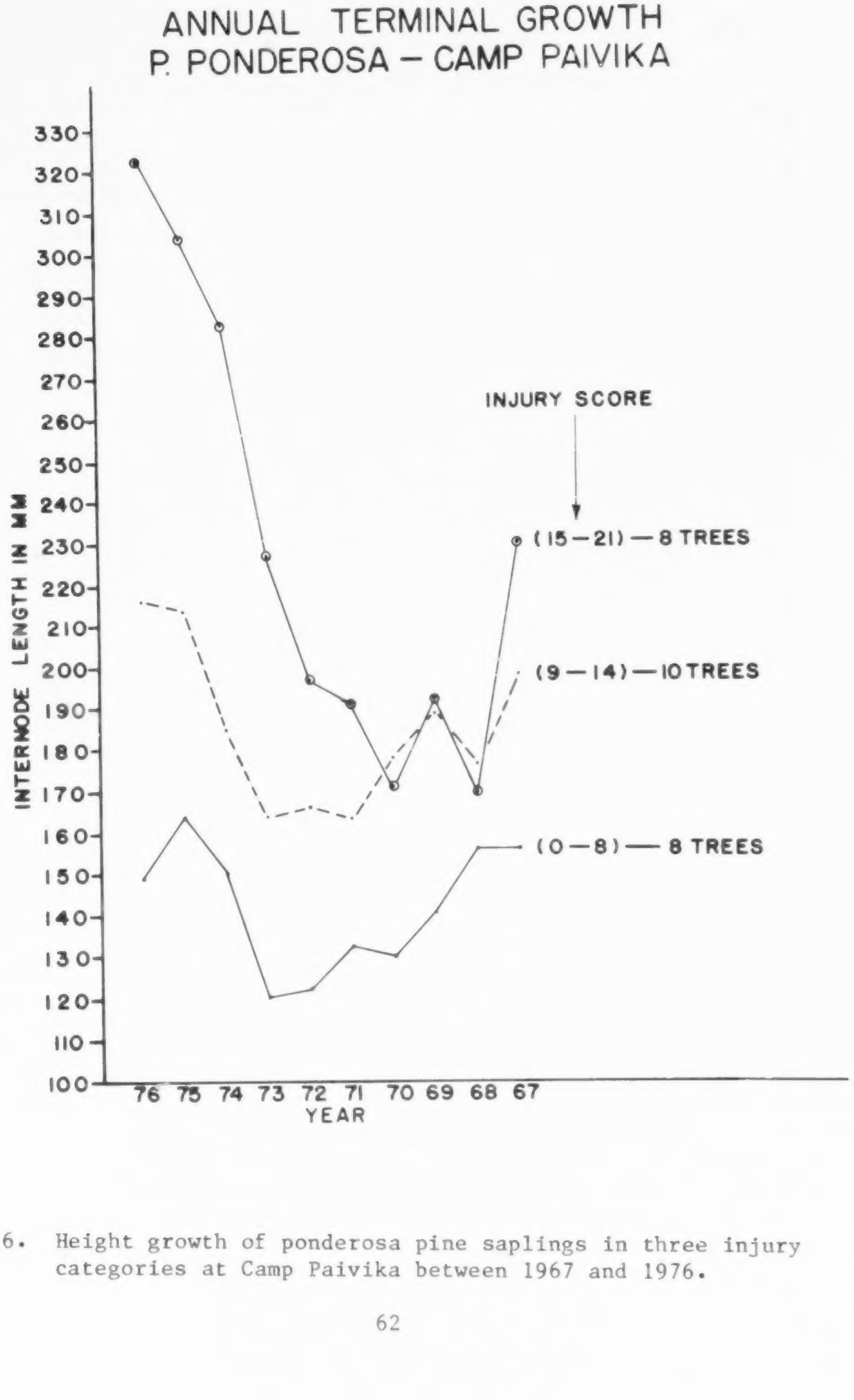

Figure 16. Height growth of ponderosa pine saplings in three injury categories at Camp Paivika between 1967 and 1976.

doses which increased towards the end of this period (see the three year moving average in Figure 9 from the nearby Sky Forest station). In a previous study, saplings were placed in carbon filtered air and even the most severely injured trees improved but there was a 2-3 year lag before the improvement in terminal shoot growth was evident (Miller, et al. 1977). Lags may make it difficult to recognize the effects of a single year with a low oxidant dose and non-limiting soil moisture. Additional analysis of the SAPGO data will be done in order to estimate the effects of the amount and the timing of oxidant dose and precipitation relative to annual shoot growth.

Annual Changes in Oxidant Injury Scores of Ponderosa and Jeffrey Pines and Tree Mortality at Major Vegetation Plots--

Oxidant injury scores--The changes in mean scores for each plot in 1976 included higher scores (improved tree condition) at most of the 18 plots. In Table 13, the changes at individual plots are shown between 1973 and 1976. In 1976, 10 plot scores were significantly higher ($p = .05$), 2 were significantly lower and the remaining 6 plots did not change significantly. The trend to improve tree condition matches the decreasing seasonal oxidant doses in 1975 and 1976 (Fig. 9).

Tree mortality--Tree deaths related to chronic oxidant injury decreased also from 26 in 1974 to 19 and 11 in 1975 and 1976 respectively. The 4-year accumulated mortality in Table 13 is expressed as percentage of the original number of ponderosa and Jeffrey pines on the 30 m wide plots. There are several exceptions where tagged trees fall outside the 30 m specification because in some cases the stands contained fewer trees ≥ 30 cm dbh; in such cases trees were selected at measured distances outside the plot (to avoid making the plot excessively long) to achieve the purpose of having 50 ponderosa or Jeffrey pines ≥ 30 cm dbh in each plot.

TABLE 13. TRENDS IN PONDEROSA AND JEFFREY PINE CHRONIC INJURY SCORES[+] AND TREE DEATH AT EIGHTEEN PERMANENT PLOTS.

	YEARS								Accumulated
	1973		1974		1975		1976		Mortality
Plot Name	Injury Score	Number Dead	Injury Score	Number Dead	Injury Score	Number Dead	Injury Score	Number Dead	1973-1976 Percent
COO	15.1	0	12.9	0	12.5	4	13.8[++]	0	6.6
BP	16.8	2	16.5	2	14.5	1	15.5	0	6.9
CP	17.0	0	16.7	2	14.7	0	17.9[++]	1	3.1
SF	13.4	1	13.8	1	15.3	2	15.0	0	3.3
DWA	20.2	0	16.5	0	16.0	2	18.2[++]	0	2.4
UCC	15.5	0	15.9	1	16.3	0	16.0	0	1.5
TUN2	19.2	0	17.0	1	17.0	1	18.6[++]	0	2.7
DL	----	-	18.6	0	19.2	1	20.7	0	1.5
GVC	21.7	0	20.1	0	23.1	0	21.0[++]	0	0
BL	29.4	0	31.8	0	30.5	1	34.5[++]	2	2.1
NEGV	33.1	0	32.1	0	40.6	1	36.0[++]	0	1.5
SC	41.3	0	47.3	0	44.5	0	46.0	0	0
HV	46.3	0	47.7	0	44.6	0	50.5[++]	0	0
SCR	12.4	0	11.7	0	12.5	1	16.7[++]	1	4.0
CA	25.6	1	17.4	2	17.9	1	17.5	1	7.3
BF(PP)	22.5	5	19.3	5	20.5	2	23.0[++]	6	10.7
BF(JP)	21.3	1	20.4	2	21.5	1	23.8[++]	0	6.9
CAO	21.7	1	24.6	9	25.7	1	33.2	0	8.9
HB	44.0	0	39.6	1	33.9	0	38.2[++]	0	0.8

[+] Score Interpretation:

1-8 = Very severe

9-14 = Severe

15-21 = Moderate

22-28 = Slight

29-35 = Very slight

36 & above = No visible injury

[++] Significant Difference (p = 0.05) between 1975 and 1976

EFFECT OF PHOTOCHEMICAL OXIDANTS ON TREE GROWTH IN THE SAN BERNARDINO NATIONAL FOREST

Introduction

History of Oxidant Impact on Tree Growth--

Symptoms of air pollution injury were first observed in the San Bernardino mountains on ponderosa pine (*Pinus ponderosa* Laws.) in 1953 (Asher 1956), although the direct link between cause and effect was not discovered until early 1960. Symptoms included loss of all but the current season's needles, reduction in number and size of needles, and yellow mottling of the needles. Miller *et al*. (1963) confirmed that these injury symptoms were produced by ozone. McBride *et al*. (1975) and Parmeter *et al*. (1962) demonstrated significant reductions in both radial and height growth increment of ponderosa pine as a result of oxidant exposure. Additional data was necessary to more completely document the impact of oxidants on tree growth and to properly calibrate a stand growth model for the SBNF.

Research Objective

1) Document the impact of photochemical oxidant injury on radial growth increment of the major tree species occurring in the SBNF.

2) To examine the mortality rates and radial growth patterns of forest trees in the SBNF with the aid of a stand development model.

Materials and Methods

Selection of Study Plots--

Six vegetation plots were selected for examination. A smog injury rating system, developed by Miller (1973), was applied to the trees on each plot. This system involves examination of a tree with binoculars and scoring it as to needle retention, needle condition, needle length and branch mortality. The six plots were then classified according to the most common injury scores. Two plots contained a majority of trees rated as severely injured, COO and BP. Two plots were rated as moderately damaged, GVC and DL; and two plots had very slight or no visible smog damage, HV and NEGV. The plots varied in length from 100 to 300 m.

Sampling Procedure--

During the summer of 1976 each conifer greater than 10 cm. dbh (diameter at breast height) on the six study plots was cored with an increment borer. The core was taken at a height of 1.5 m on a randomly chosen side of the tree trunk. The cores were returned to the laboratory, dried at 70°C for 24 hours, mounted on boards and sanded, aged and the growth rings measured to the nearest 0.01 mm back to and including the year 1920. Each tree was classified as to the soil type on which it occurred.

Statistical Analysis--

Growth data from trees within and between stands was quite variable. To reduce this variation as much as possible it was felt that the trees should be stratified before analysis. Trees were divided into groups delineated by species, plot, age and soil type. Within each group the growth data for the past 30 years (excluding 1976) was considered for analysis (i.e., 1946-1975). This period was divided into ten year growth periods; 1946-1955, 1956-1965, 1966-1975. A period of this length (30 years) should be adequate to detect growth trends as influenced by photochemical oxidants which have steadily been increasing in recent years (Corn *et al*. 1975).

Examining the growth rings on a tree core is, in actuality, sampling the growth of a given tree through time. This situation lends itself to examination using a repeated measure analysis of variance (ANOVA) design (Sokal and Rohlf, 1969).

No statistical tests were performed to compare growth between plots. Since so many variables among them are different it was felt that they were not quantitatively comparable. However, it was felt that, qualitatively, the growth trends for two similarly stratified tree groups on different plots could be compared.

Results and Discussion

Impact of Oxidant on Radial Increment--

Radial growth of forest trees can be affected by many different phenomena. In order to examine the effects of oxidants on tree growth it is necessary to eliminate other variables that affect tree growth to ensure that there are no confounding interactions among these variables. One important variable influencing tree growth is precipitation. One weather station in the vicinity of the SBNF was selected as being most representative of the precipitation in the SBNF (Squirrel Inn #2). The precipitation records for the years in question are presented in Table 14. A one way analysis of variance was performed on these data to detrmine if any significant differences in precipitation existed among the three growth periods and none were found. Therefore, significant differences in radial growth among the three growth periods cannot be directly attributed to rainfall.

It was necessary to insure that tree growth was not correlated with precipitation during the years encompassed by this study. Mean annual precipitation, recorded at 3 weather stations in close proximity of the

TABLE 14. ANNUAL PRECIPITATION (cm) AT SQUIRREL INN #2 WEATHER STATION AND AN ANALYSIS OF VARIANCE AMONG THE TEN YEAR INTERVALS THAT CORRESPOND TO THE TEN YEAR GROWTH PERIODS.

1946	35.89	1956	125.78	1966	151.33
1947	83.29	1957	113.46	1967	49.05
1948	109.32	1958	62.26	1968	200.25
1949	55.85	1959	73.74	1969	91.59
1950	99.26	1960	45.16	1970	88.54
1951	147.32	1961	87.05	1971	35.13
1952	36.68	1962	86.59	1972	102.13
1953	120.19	1963	76.07		
1954	78.97	1964	169.88		
1955	63.35	1965	90.27		
n	10		10		7
$\bar{X}$	83.01		93.03		102.57
Sx	34.61		33.73		52.98

Source	d.f	SS	MS	F	
Between Periods	2	1599.915	799.958	.446	ns
Within Periods	24	43009.607	1792.067		
Total	26	44609.522			

Reject H_o if $F > F_{2;24/.05} = 3.40$

specific study plots, is presented in Table 15. Mean annual radial growth from several trees on each plot was used in a regression analysis with mean annual precipitation from the appropriate weather station. No significant correlations were found between tree growth and precipitation.

Plot size, number of individual trees per plot, species composition, density, and basal area for each plot are described in Table 16. Data for the Deer Lick plot is incomplete.

COO and BP, the two plots that have a severe smog injury rating, were the only two plots that showed significant changes in radial growth trends (Table 17, Figs. 17 to 22). Growth in all of the tree groups in COO shows a significant reduction (Fig. 17) but this trend was not as distinct in the BP plot (Fig. 18).

In the first growth period (1945-55), the yearly radial growth increment for trees in COO was much greater compared to growth in the other plots, and was still slightly greater in most groups even after drastic reductions by 1975 (Table 17, Figs. 17-22). This could be explained, in part, by the predominately younger age groups in the COO plot, since younger trees tend to grow faster than older trees. The site class of COO may also be higher. Trees in the BP plot were older than most of the trees in COO and showed a more variable growth response. Older trees may not react as strongly to oxidant exposure as young trees. The youngest group of trees in BP were the fastest growing in 1945-56 and showed the strongest decrease in growth through time. Faster growing trees may also react more to oxidant exposure than slower growing trees. Since the youngest trees were usually the faster growing individuals it is impossible to determine which factor may be responsible for this strong reaction to oxidant exposure.

TABLE 15. RAINFALL DATA FOR THE SIX STUDY PLOTS (MEAN ANNUAL PRECIPITATION cm)

	1946-55	1956-65	1966-75
Green Valley Weather Station for COO, GVC, DL, NEGV	---[+]	84.28	86.21
Panorama Point Weather Station for BP	---[+]	61.74	80.92
Big Bear Dam Weather Station for HV	83.84	86.59	97.94

[+] No available data.

White fir trees on COO are affected just as severely as the pine (Fig. 17) while incense cedar on BP did not seem to be responding to oxidant exposure (Fig. 18).

The two plots rated as moderately damaged (GVC and DL) showed no growth response to oxidant exposure (Table 17, Figs. 19 and 20). The presence of visible foliar damage on these plots may indicate a threshold phenomenon. Visible injury, or oxidant exposure, may need to reach a certain level before radial growth increment is affected. Another explanation may be that oxidant impact on radial growth may not be expressed in the bole of the tree at 1.5 m but may cause measurable increment loss within the crown. Williams (1967) demonstrated that spruce budworm defoliation reduced radial increment of grand fir, Douglas-fir, and Englemann spruce to a greater extent within the crowns than near the ground. The same simulation may exist here.

The two plots with slight or no visible smog injury (HV and NEGV) showed some significant growth trends (Table 17, Figs. 21 and 22). The Jeffrey pine over 200 years old in NEGV show a significant but small increase in growth (Fig. 21). This defines no signicant trend in growth. Jeffrey pine on the HV plot from 41-50 and 51-60 years old showed a significant but small decline in growth. This reduction was probably due to the natural, gradual decline in radial growth increment at breast height that occurs as a tree ages (Duff and Nolan, 1953).

The younger trees of each species are growing faster than the older trees of the same species on any given plot. White fir is the fastest growing tree on each plot when compared to other species of the same age. It appears to be better adapted for faster growth than the other tree species in the San Bernardino mountains but is just as susceptible to oxidant injury as ponderosa pine.

Not all species occurred on each plot so it is not possible to make statements on their susceptibility to specific levels of oxidant injury.

Stand Development Model--

The data collected from the six study plots has been sent to Dr. A. R. Stage, U. S. Forest Service, Intermountain Forest and Range Experiment Station, Moscow, Idaho to be run through his Stand Prognosis Model. No results have been obtained from this effort to date. Work on this aspect of the project will continue.

TABLE 16. MENSURATIONAL DESCRIPTIONS OF THE SIX SAMPLE PLOTS.

		PP	SP	IC	WF	JP	BO	QW	CL
COO	No. of Trees/ Plot	46	1	3	20		39		
170m	Spp. Composition(%)	37	1	2	16		31		
Severe Damage	Density (#/ha)	90.2	2.0	5.9	39.2		76.5		
	Basal Area (m^2/ha)	14.52	.72	1.53	6.00		4.80		
BP	No. of Trees/ Plot	71		30			31	1	
100m	Spp. Composition(%)	43		22			23	1	
Severe damage	Density (#/ha)	236.7		100.0			103.3	3.3	
	Basal Area (m^2/ha)	28.10		11.86			4.08	0.04	
GVC	No. of Trees/ Plot		11	10	62	39	82	1	
300m	Spp. Composition(%)		4	4	26	16	35	1	
Moderate damage	Density (#/ha)		12.2	11.1	68.9	43.3	91.1	1.1	
	Basal Area (m^2/ha)		2.93	1.63	4.94	12.20	4.70	0.02	
NEGV	No. of Trees/ Plot				8	65			
180m	Spp. Composition(%)				10	89			
No damage	Density (#/ha)				14.8	120.4			
	Basal Area (m^2/ha)				1.05	35.00			

TABLE 16. CONTINUED.

		PP	SP	IC	WF	JP	BO	QW	CL
HV	No. of Trees/ Plot				24	168	4		5
290m	Spp. Composition(%)				11	83	1		2
No damage	Density (#/ha)				27.6	193.1	4.6		5.7
	Basal Area (m^2/ha)				3.4	22.07	.21		0.13
DL	No. of Trees/ Plot		22		32	55	40		
120m	Spp. Composition(%)		15		21	37	27		
Moderate damage	Density (#/ha)		--		--	--	--		
	Basal Area (m^2/ha)		--		--	--	--		

Table Legend

PP	Ponderosa pine	JP	Jeffrey pine
SP	Sugar pine	BO	Black Oak
IC	Incense Cedar	QW	*Quercus wislizenii*
WF	White fir	CL	*Cercocarpus ledifolius*

Note: From McBride, J. R. 1974. Annual report of the vegetation subcommittee for the fiscal year ending. In: Taylor, O. C. Oxidant air pollution effects on a western coniferous forest ecosystem. Task D. Statewide Air Pollution Research Center, Riverside, California.

TABLE 17. AGE GROUPS, SOIL TYPES, MEAN ANNUAL RADIAL GROWTH INCREMENT (mm) AND STANDARD DEVIATION FOR EACH GROWTH PERIOD, F VALUES FROM ANOVA, AND EXPLAINED VARIANCE (ω^2) FOR EACH STRATIFIED GROUP OF SAMPLE TREES ON EACH PLOT.

COO Age	Soil Type	n	1946-55	1956-65	1966-75	F	ω^2
PP 51-60	PxClCm	9	3.26 ± .92	2.13 ± .65	1.33 ± .76	23.24	.510
PP 51-60	PxClDm	9	2.89 ± .54	1.96 ± .38	1.64 ± .90	23.77	.401
PP 41-50	PxClEm	9	3.39 ± 1.55	2.36 ± 1.14	1.48 ± 1.00	16.22	.280
PP 41-50	PxClDm	9	3.76 ± 1.29	2.25 ± .97	.78 ± .33	55.87	.620
WF 41-118	PxClEm	7	3.87 ± .75	3.24 ± .98	2.47 ± .98	6.92	.286
BP							
PP 61-100	PHclCm	15	1.25 ± .65	1.52 ± .65	1.75 ± .62	n.s.	---
PP 41-60	PHclCm	8	1.96 ± .58	1.21 ± .68	.56 ± .21	27.00	.542
PP 61-100	PHclDm	38	1.51 ± .74	1.78 ± .67	1.17 ± .72	6.65	.047
IC 61-100	PhclDm	15	1.78 ± .85	1.58 ± .66	1.87 ± .81	n.s.	---
GVC							
JP 61-200	TsEm	14	.87 ± .41	.76 ± .34	.69 ± .50	n.s.	---
WF 61-200	ExsaDm	14	1.20 ± .53	1.07 ± .53	1.33 ± .89	n.s.	---
WF 51-60	TsEm and ExsaDm	9	1.80 ± .85	1.90 ± .76	1.92 ± .81	n.s.	---
SP 41 or older		10	1.28 ± .58	1.29 ± .73	1.55 ± .81	n.s.	---
IC over 31		7	1.85 ± .81	1.23 ± .58	1.38 ± .82	5.81	.112
DL							
JP 101-200	no data available	33	.55 ± .33	.52 ± .34	.44 ± .31	10.94	.022
SP 61-200	no data available	17	.88 ± .37	.89 ± .34	1.00 ± .39	3.39	.022
WF 61-200	no data available	19	1.09 ± .40	1.17 ± .41	1.17 ± .38	n.s.	---
NEGV							
JP over 200	TsEf	17	.45 ± .16	.45 ± .22	.56 ± .78	4.37	.046
JP 101-200	TsEf	20	.77 ± .49	.79 ± .42	.77 ± .34	n.s.	---

TABLE 17. (continued)

HV	Age	Soil Type	n	1946-55	1956-65	1966-75	F	ω^2
JP	over 200	TAf1Dm	9	.60 ± .22	.43 ± .14	.43 ± .18	7.48	.166
JP	41-50	TAf1Cm	34	1.74 ± .68	1.24 ± .55	1.21 ± .68	43.43	.126
JP	51-60	TAf1Cm	22	1.53 ± .63	1.04 ± .53	1.11 ± .64	26.77	.114
JP	61-100	TAf1Bm	17	.75 ± .39	.64 ± .38	.65 ± .42	n.s.	---
WF	61-100	TAf1Bm	12	1.00 ± .56	.92 ± .46	1.04 ± .64	n.s.	---

Table Legend:

Code	Soil Type
PxC1Cm	Pachic Xerumbrept on 5-10% slopes
PxC1Dm	Pachic Xerumbrept on 19-23% slopes
PxC1Em	Typic Xerorthent
PHc1Cm	Pachic Ultic Haploxerolls on 10-15% slopes
PHc1Dm	Pachic Ultic Haploxerolls on 15-30% slopes
TsEm	Typic Xeropsamments
ExsaDm	Entic Xerorthents
TsEf	Typic Xeropsamments
TAf1Dm	Typic Argixerolls on 15-20% slopes
FAf1Cm	Typic Argixerolls on 9-15% slopes
TAf1Bm	Typic Argixerolls on 3-9% slopes

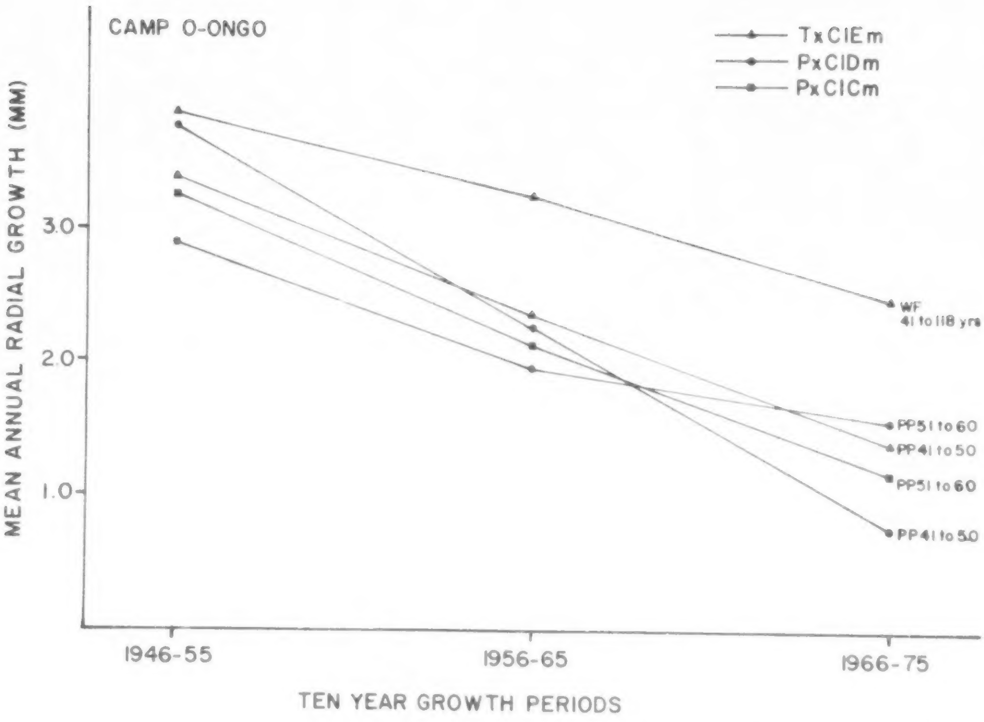

Figure 17. Growth trends for trees on the COO plot from 1946 to 1975 in the San Bernardino National Forest.

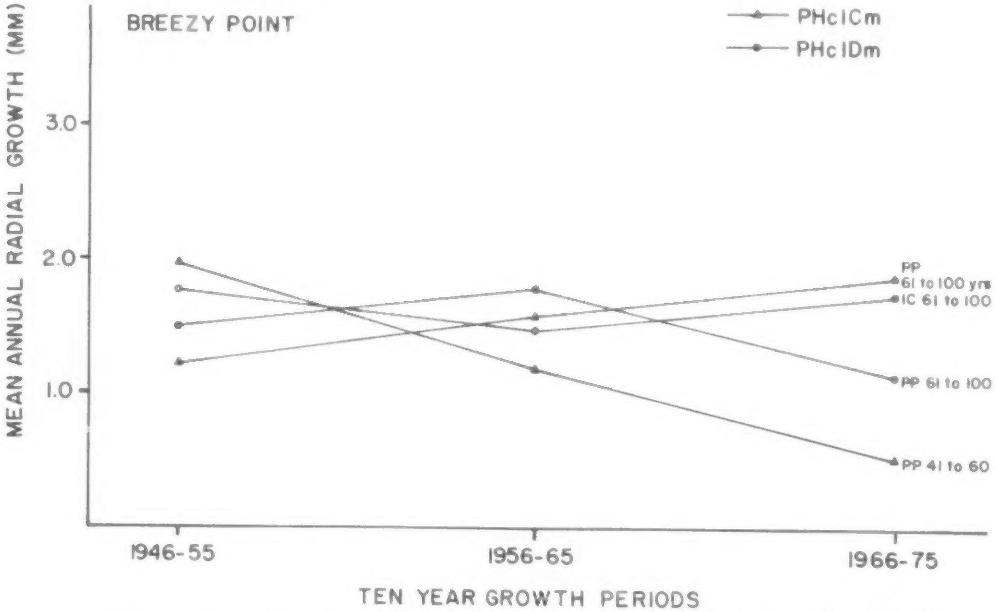

Figure 18. Growth trends for trees on the BP plot from 1946 to 1975 in the San Bernardino National Forest.

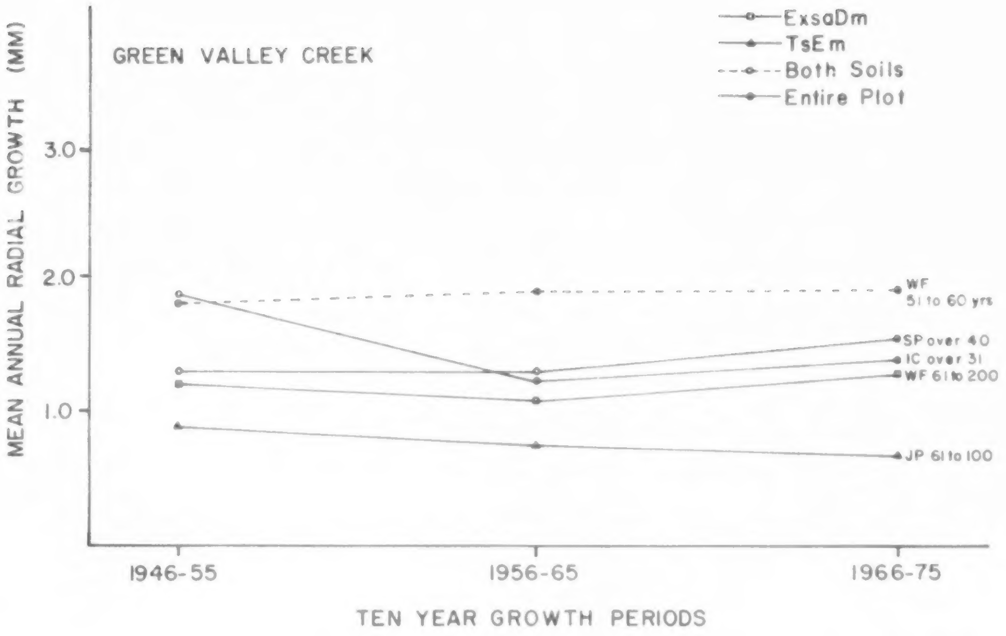

Figure 19. Growth trends for trees on the GVC plot from 1946 to 1975 in the San Bernardino National Forest.

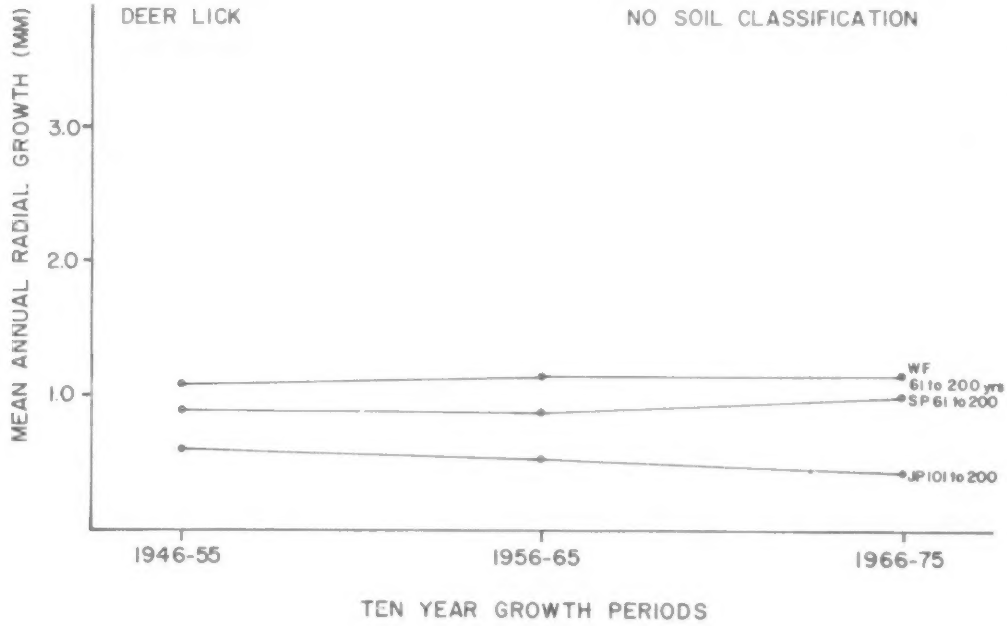

Figure 20. Growth trends for trees on the DL plot from 1946 to 1975 in the San Bernardino National Forest.

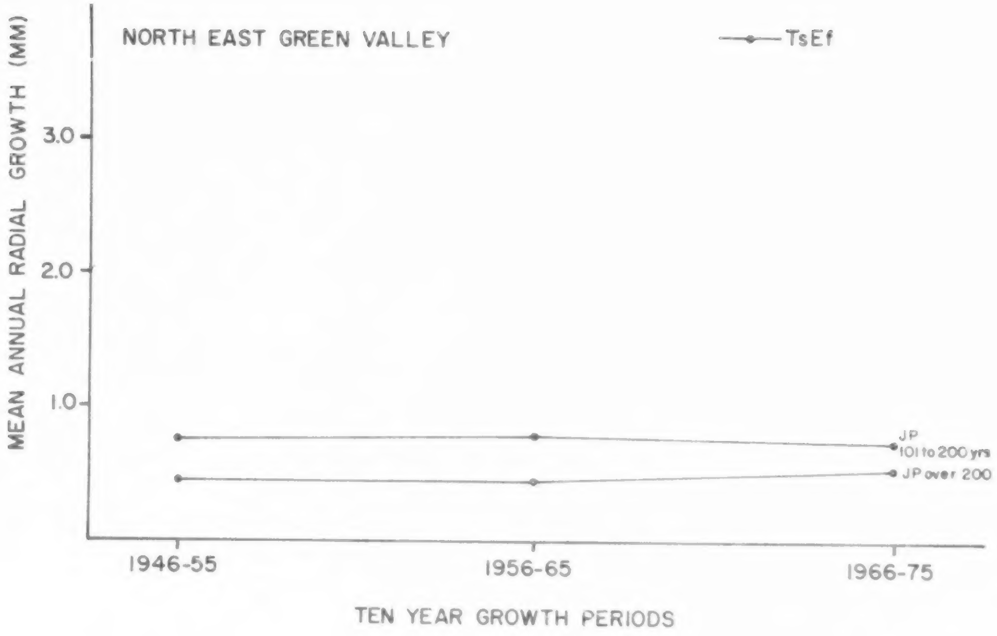

Figure 21. Growth trends for trees on the NEGV plot from 1946 to 1975 in the San Bernardino National Forest.

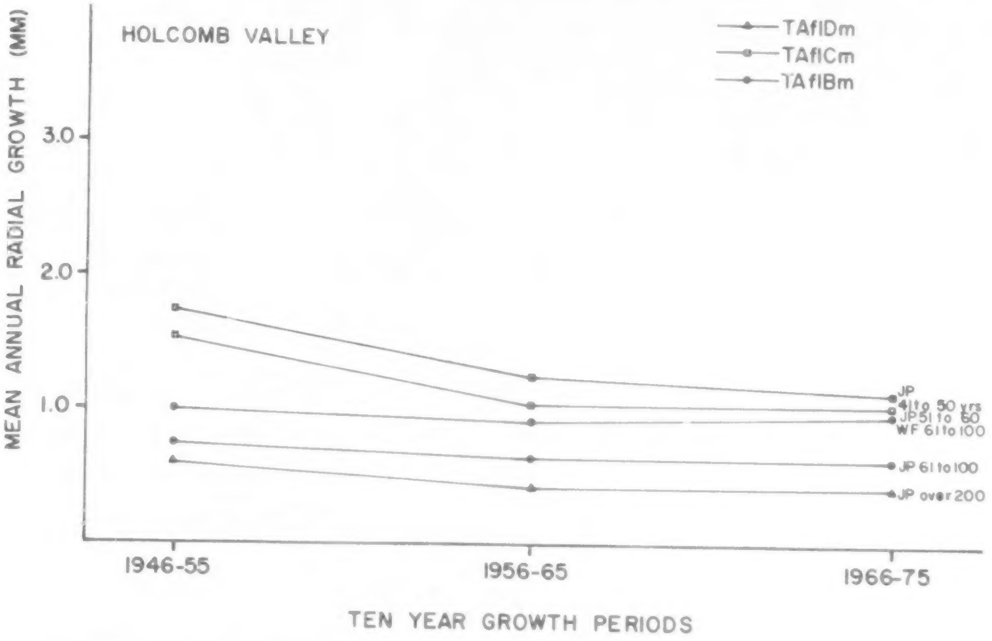

Figure 22. Growth trends for trees on the HV plot from 1946 to 1975 in the San Bernardino National Forest.

PHYSICAL AND CHEMICAL PROPERTIES OF SOILS, INCLUDING MOISTURE DYNAMICS

Introduction

During 1976-'77 the questions addressed were (1) What are the soil moisture and temperature regimes and how do they relate to the susceptibility of the vegetation to damage during periods of high oxidant air pollutant concentrations and do they affect the impact of oxidants on other organisms such as pathogenic fungi, arthropods and litter decomposing organisms? (2) How do physical properties of the soils affect these moisture and temperature relationships? (3) Do the plant nutrients in and chemistry of the soil affect the relationships described above? In this context, three kinds of soil characterization measurements carried out were: soil moisture retention properties; soluble soil phosphorous; and identification of the soil and slope with each tree on the major vegetation plots. The first two characterization measurements were descriptive of the system.

Soil moisture and temperature data collected continuously since summer 1973 can be used to document the complete water balance including periods of soil moisutre deficit. This data will then be related to the physiological conditions of the vegetation measured as xylem water potential and transpiration rate.

Material and Methods

Soil Moisture and Temperature Measurement--

Soil moisture-temperature sensors (fiberglass moisture blocks) installed at depths of 15, 31, 61, 92, 152, 214 and 274 cm were monitored every one to three weeks depending upon the rate of change. Field readings from the moisture sensor were converted to percent water content (Pw) based upon calibration curves for soil at each sensor site. Soil samples were collected at the sensor sites and water content was determined in the laboratory to construct the calibration curves. The values obtained were used mainly to describe the shape of the curves of soil moisture change with time. The values were then adjusted based upon soil moisture content determined by mechanically sampling of the soil at the same depths as the moisture blocks with an auger boring within 1.5 meters of the site of the sensors. Moisture retention data also determined on the same sensor-site samples were used as a further check upon the accuracy of the final corrected values. This procedure was adopted because of the very large number of moisture sensors emplaced in the field. Soil temperature was read directly from the sensors by means of calibration data stored in the computer program. Both soil moisture and temperature can be monitored for accuracy by comparing the results from a given sensor with those above and below it in the soil column. Any erratic behavior can be readily detected and corrected. A few sensors failed and were replaced due mainly to the wire leads being bitten off by pocket gophers. The sensors were remarkably stable and consistent in their behavior.

Nature and Pattern of Soils--

Detailed slope and soil classification and mapping completed previously on 18 major vegetaton plots were used to characterize the slope and soil under each pine tree on the plots in order to develop relationships of soil and stand dynamics.

Soil properties measured--Particle size distribution, bulk density, exchangeable and soluble cations, soil pH, organic matter and nitrogen were previously measured in the soils on major vegetation plots (Miller et al., 1977) During the 1977-'78 period soluble phosphate was measured on 138 surface soil samples taken under 40 trees selected for their relationships to other subprojects dealing with arthropods, litter decompositon, and pathogenic fungi. The latter completes the analyses of the surface soil samples, reported previously, which included organic carbon, nitrogen, exchangeable sodium, potassium, calcium and magnesium.

Specific analytical procedures--Moisture retention was determined on soils from all major vegetation plots and on two aspect plots at the same sites used for soil moisture monitoring by fiberglass moisture block sensors. Soil moisture tension was measured at 0.1, 0.33, 1, 5 and 15 atmospheres by the methods described by Richards in the book edited by Black (1965). However, duplicate 1.0 cm rings were used rather than 5 cm diameter rings described in the method for holding the soil on the tension and pressure plates. Soil moisture retention was determined on each site at depths of 15, 61, 91 cm and over 200 cm for deep soils. Soluble phosphorous was determined by a colorimetric method (Jackson, 1960) for the surface soils collected to a depth of 7.5 cm of soil.

Results and Discussion

Soil Moisture Retention Characteristics--

The computer programs for processing the large amount of data (over 8,000 field readings on the 153 sensors) has been completed and complete curves were plotted from summer of 1973 to date (summer 1977). These curves were not adjusted for the gravimetric control moisture sampling and so are not included in this report. Adjusted curves are being prepared, and will be made available for all participants in the project soon. However, inspection of the nonadjusted curves show that the moisture-temperature sensors have been remarkably stable throughout the 5 year period, in that the maxima of winter moisture and summer minima are nearly the same each year. Also the shape of the moisture depletion curves vary from year to year, and with increased depth of soil or variation in soil texture. Further, errors in field readings are readily detected as indicated by individual variations from the smooth curves not accounted for by sudden rainfall or abrupt changes in air temperature which may affect the upper sensors.

It appears that the soil moisture-temperature monitoring during the 5 year period has been eminently successful and can be used effectively in evaluating soil relationships to the impact of oxidant air pollution on the ecosystem. Rates of soil moisture depletion will be related to transpiration by the vegetation and to moisture stress on the plants.

The results of the analyses are shown in Table 18 and 19 and a typical set of moisture retention curves are shown in Figure 23. Water held in the soil at low tension (0.1 atm.) is an approximation of field capacity of the soil to hold water when freely drained. The minimum water content which is available for plant use is considered to be about 15 atm; this minimum is called the permanent wilting point. Difference is an approximation of the amount of water that can be stored in the soil which is available for plant growth. Values of the differences in percent water for the major vegetation plots are shown in Table 20 and are called "available soil water". However, these values are only approximations and do not always agree well with measurement of samples taken directly from the field, and should be used with caution. They will be used to help in calibrating the soil moisture monitoring program, and for direct measurement of soil moisture sampled when wet in the spring and when dry in the late summer or fall. "Available soil water" indicated in Table 20 ranges from 7.17 and 7.35 percent by weight (Pw) in the two plots with the sandiest textures to nearly 24 percent in the surface of a number of plots where the soil is rich in organic matter. Available soil water tends to increase with increased clay content in the upper layers of these sandy soils, but there appears to be little relationship between the two variables below 61 cm.

TABLE 18. SOIL WATER CONTENT AT VARIOUS MATRIC SUCTIONS FOR THREE PROFILE DEPTHS.

		P_w 1/10 BAR			P_w 1/3 BAR	
Site	0-30	30-61	61-91 cm	0-30	30-61	61-91 cm
BF	31.73	26.88	23.02	20.97	15.24	13.84
BL	18.31	15.78	12.23	11.55	8.37	7.42
CAO	20.79	20.45	19.44	14.98	12.91	13.77
DW2	22.48	22.22	17.86	17.48	13.82	12.83
GVC	13.87	14.88	12.59	10.64	10.25	8.82
HV	16.72	12.89	13.05	11.50	8.99	8.94
NE12	25.63	18.59	17.29	18.03	12.82	11.98
NEGV	13.22	12.85	11.10	9.21	7.71	6.65
SC1	11.73	12.20	13.85	8.74	7.87	8.28
SC2	14.22	13.45	11.17	9.47	6.77	5.83
SV2	16.56	n.d.	n.d.	13.05	6.59	n.d.
UCC	20.44	21.04	20.07	15.90	14.65	15.26
BP	26.87	25.00	21.66	18.18	16.05	17.88
COO	22.30	18.40	17.00	17.03	12.85	13.55
DW1	26.29	18.80	19.02	17.40	13.45	15.62
DW3	24.04	22.20	17.66	16.77	13.65	13.32
HB	15.79	11.90	12.36	11.19	7.47	9.42
CP	27.73	24.50	n.d.	19.83	15.74	n.d.
S22M	26.15	20.30	18.63	20.97	14.31	14.56
SCR	10.54	10.90	10.50	6.38	5.93	7.07
SF	29.40	25.90	21.21	21.36	17.17	17.71
TUN2	19.11	17.20	n.d.	13.91	11.00	n.d.

TABLE 18. CONTINUED

		P_w 1 BAR			P_w 5 BAR	
Site	0-30	30-61	61-91 cm	0-30	30-61	61-91 cm
BF	14.61	10.15	9.28	8.81	6.30	5.79
BL	8.29	5.31	5.25	5.39	3.54	3.54
CAO	11.25	9.04	9.72	6.33	5.78	6.38
DW2	12.55	10.21	9.22	7.46	6.40	6.29
GVC	7.89	7.52	6.49	3.97	4.15	4.00
HV	8.59	7.25	7.07	6.23	5.46	5.36
NE13	12.60	8.83	8.45	7.59	5.27	5.44
NEGV	6.52	5.36	5.25	4.30	3.38	3.15
SC1	6.69	6.09	6.25	5.00	4.77	4.74
SC2	6.99	4.66	4.29	5.66	3.14	2.93
SV2	9.32	4.58	n.d.	5.21	2.68	n.d.
UCC	11.09	11.60	12.27	5.60	8.40	9.52
BP	12.55	12.10	13.29	7.96	7.04	7.57
COO	12.53	10.34	9.86	8.50	7.08	7.25
DW1	11.91	9.24	10.30	7.08	5.82	7.04
DW3	10.76	10.43	8.54	7.06	6.34	5.58
HB	6.26	5.72	6.39	4.09	3.47	4.42
CP	13.39	12.45	n.d.	8.86	8.33	n.d.
S22M	13.38	11.65	9.92	7.48	6.58	6.29
SCR	5.15	4.56	4.14	4.11	2.92	2.66
SF	14.74	13.34	10.96	9.00	8.00	6.94
TUN2	8.80	7.71	n.d.	4.74	4.24	n.d.

TABLE 18. CONTINUED

	P_w 15 BAR		
Site	0-30	30-61	61-91 cm
BF	7.86	5.84	5.43
BL	5.08	3.32	3.25
CAO	5.27	5.25	5.95
DW2	6.58	6.16	6.15
GVC	3.31	3.71	3.62
HV	5.66	5.15	5.18
NE13	6.58	4.87	5.15
NEGV	3.94	3.25	3.06
SC1	4.56	4.64	4.51
SC2	5.13	3.14	2.71
SV2	4.36	2.37	n.d.
UCC	4.78	7.91	9.09
BP	6.95	6.47	8.16
COO	6.97	6.44	8.64
DW1	5.90	5.23	6.92
DW3	6.20	5.80	5.06
HB	3.45	2.95	4.07
CP	7.42	7.84	n.d.
S22M	6.00	5.99	5.54
SCR	3.19	2.44	2.33
SF	7.46	7.18	6.20
TUN2	3.81	3.93	n.d.

TABLE 19. SOIL WATER CONTENT AT VARIOUS MATRIC SUCTIONS FOR PROFILE DEPTHS OF 200 CM OR GREATER.

Site	1/10 BAR 200 cm	1/3 BAR 200 cm	1 BAR 200 cm	5 BAR 200 cm	15 BAR 200 cm
BP	12.33	7.62	6.42	4.70	4.23
COO	10.73	4.14	2.97	2.19	1.87
SCR	10.09	6.22	4.36	2.75	2.49
SF	22.94	18.62	12.43	7.21	6.65
BL	10.50	6.45	3.86	1.80	1.63
DW2	17.69	12.92	8.85	4.98	4.71
GVC	11.45	7.55	4.89	3.15	2.84
NE13	15.56	9.37	6.50	3.73	3.50
UCC	17.06	11.40	9.23	6.30	5.89

TABLE 20. AVAILABLE SOIL WATER AND CLAY CONTENT AS PERCENT OF THE WHOLE SOIL FOR THREE SOIL DEPTHS.

	0-30 cm		30-61 cm		61-91 cm	
Site	Pw	% Clay	Pw	% Clay	Pw	% Clay
BF	23.87	9.0	21.04	7.8	17.59	7.6
BL	13.23	4.9	12.46	3.6	8.98	4.6
CAO	15.52	9.9	15.20	10.6	13.49	13.0
DW2	15.90	5.4	16.06	4.1	11.71	6.3
GVC	10.56	4.9	11.17	2.3	8.97	2.7
HV	11.06	9.1	7.74	9.6	7.87	7.9
NE13	18.05	7.4	13.72	6.9	12.14	6.3
NEGV	9.28	4.4	9.60	4.3	8.04	2.1
SC1	7.17	5.4	7.56	3.9	9.34	2.8
SC2	9.09	5.6	10.31	4.4	8.46	2.9
SV2	12.20	6.8	6.63	4.0	n.d.	n.d.
UCC	15.66	4.9	13.13	12.7	10.98	14.3
BP	19.92	7.9	18.53	6.4	13.50	6.2
COO	15.33	6.3	11.96	5.0	8.36	8.6
DW1	20.39	6.3	13.57	6.7	12.10	11.2
DW3	17.84	8.9	16.40	8.9	12.60	8.4
HB	12.34	5.0	8.95	4.7	8.29	9.4
CP	20.31	7.9	16.66	7.9	n.d.	n.d.
S22M	20.15	7.9	14.31	7.1	13.09	7.2
SCR	7.35	3.0	8.46	3.2	8.17	3.3
SF	21.94	10.3	18.72	9.5	15.01	7.0
TUN2	15.30	5.2	13.27	5.6	n.d.	n.d.

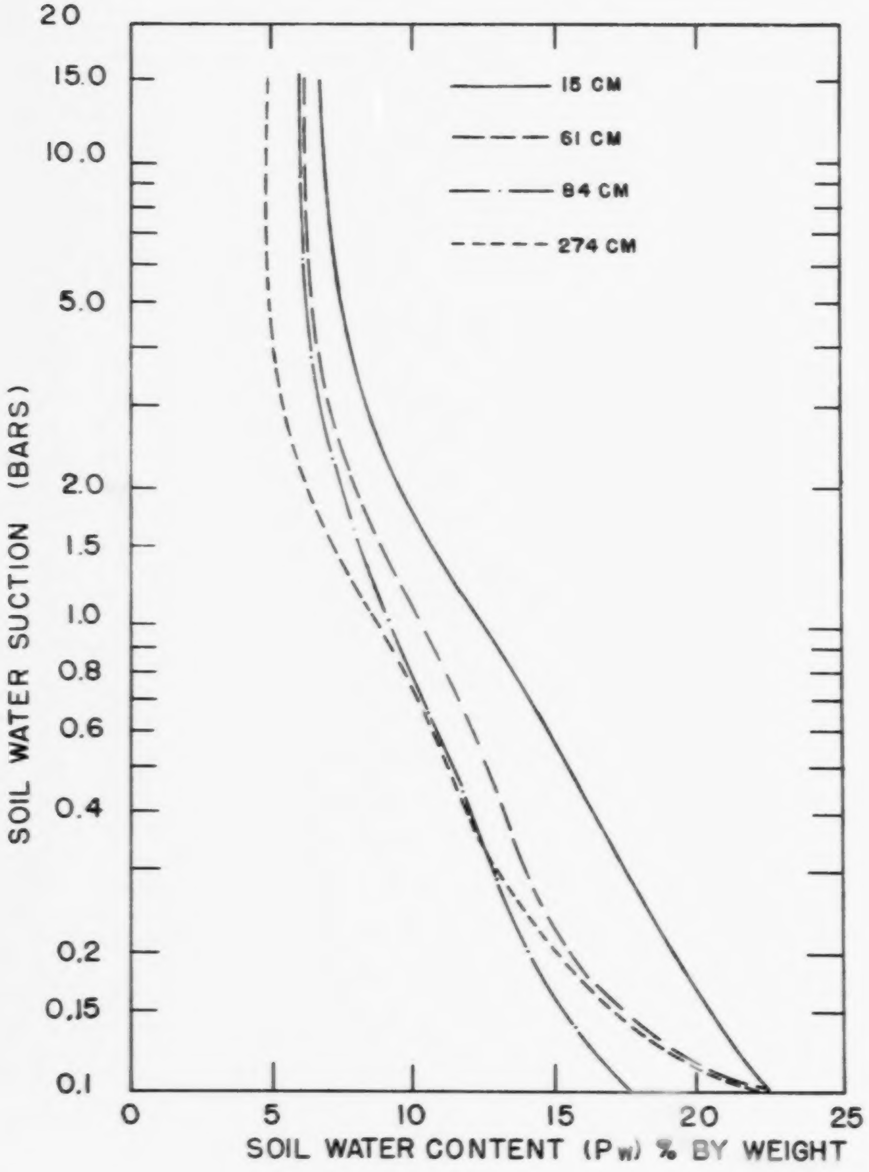

Figure 23. Moisture retention curves for Dogwood Plot Site 2.

STAND TREE MORTALITY SUBSYSTEM--BARK BEETLE POPULATION DYNAMICS

Introduction

Bark beetles in the genus *Dendroctonus* attack and kill conifers. Except in epidemics (the last large outbreak in California was in 1962-63) these beetles attack and kill trees that have been weakened or stressed physiologically. Some factors that predispose trees to attack are drought, flooding, lightning strikes, mechanical injury due to logging, building or road construction, and root disease. Photochemical oxidants likewise predispose trees to attack by bark beetles and this has been reviewed by Cobb *et al*. (1968).

Three species of bark beetle, *Dendroctonus brevicomis* Le Conte, *D. ponderosae* Hopkins, and *D. jeffreyi* Hopkins, attack and kill pines in the San Bernardino National Forest (SBNF). White fir engraver, *Scolytus ventralis* Le Conte, *Ips emarginatus* and *Melanophila california* Van Dyke are also important species in the pest complex in SBNF. Pines were chosen for this study because ponderosa and Jeffrey pines are more susceptible to oxidant air pollutants than other major tree species in the forest. A major part of the study was focused on the *Dendroctnous* genera of insects because they appeared to be more important in the SBNF than other genera. The California flathead borer, *M. california* Van Dyke, on Jeffrey pine appears to be of little importance but it may be recognized as a significant part of the pest complex on ponderosa pine when the data are analyzed. *Ips emarginatus* is found in the pest complex on Jeffrey pine 22% of the time (Fig. 1 in McBride, Dahlsten and Cobb, in Miller 1977) and could be considered important. The three Dendroctonus species alluded to above were the only bark beetles studied and by far the greatest effort was on the western pine beetle, *D. brevicomis*. An earlier study (Stark *et al*., 1968) on the SBNF showed that as the severity of oxidant damage to ponderosa pine increased, the incidence of western pine beetle and mountain pine beetle, *D. ponderosae* infestations increased. Further substantiation of the interaction between oxidant damage to pines and the incidence of bark beetles was gathered by Wood (1971). A historical analysis on the Lake Arrowhead District of the SBNF showed substantial increases in bark beetle caused tree mortality since 1951. These data were obtained by examining the beetle control records.

Research Objectives

The general objectives of the study were to determine susceptibility of predisposed trees to bark beetles and the nature of the interrelationship between oxidant damaged trees and beetle populations. Specifically the objectives were as follows:

1) To determine the degree of susceptibility of oxidant-injured

ponderosa pine to the western pine beetle and the mountain pine beetle and of Jeffrey pine to the Jeffrey pine beetle and the California flatheaded borer.

2) To investigate the influence of oxidant-injured pine trees on the success and productivity of broods of the four beetle species listed in objective #1.

3) To study the direct and indirect influence of photochemical oxidants on the biology of bark beetles, with particular emphasis on the insect associates, parasitoids, and predators.

4) To develop life tables for bark beetles by oxidant injury categories and, based on these tables, to develop predictive models of beetle activity with reference to stand type and pine oxidant-injury level.

5) To determine the biological impact and relative importance of each of the beetle species in forest communities and what influence they have on stand change and forest succession.

Methods and Materials

Western Pine Beetle--

Field sampling procedures and laboratory analyses have been described in detail for the western pine beetle (Dahlsten, 1974 and Dahlsten, 1977) and are summarized in, Figure 24. Basically each beetle generation was sampled twice or three times if it was an overwintering generation. Four different procedures were used so that each developmental stage of the western pine beetle and the insect associates, parasitoids, and predators could be accounted for. The type of information taken is shown in Figure 24 as well as in Tables 21 through 33.

Mountain Pine Beetle and Jeffrey Pine Beetle--

Procedures for the development of an optimum sampling design for the mountain pine beetle on ponderosa pine and the Jeffrey pine beetle on Jeffrey pine have been described previously (Dahlsten, 1974 and Dahlsten, 1977). A nested sampling design was used for paired samples taken at the lower, mid and upper portions of six beetle infested Jeffrey pines and five infested ponderosa pines. The optimum design is one which for a fixed variance yields the lowest cost or for a fixed cost yields the lowest variance. Four sample sizes were used and several population attributes were measured, three are indicated on the figures and tables.

Variances were estimated for each sample size for each variable within heights, within trees, and between trees using the following formulas:

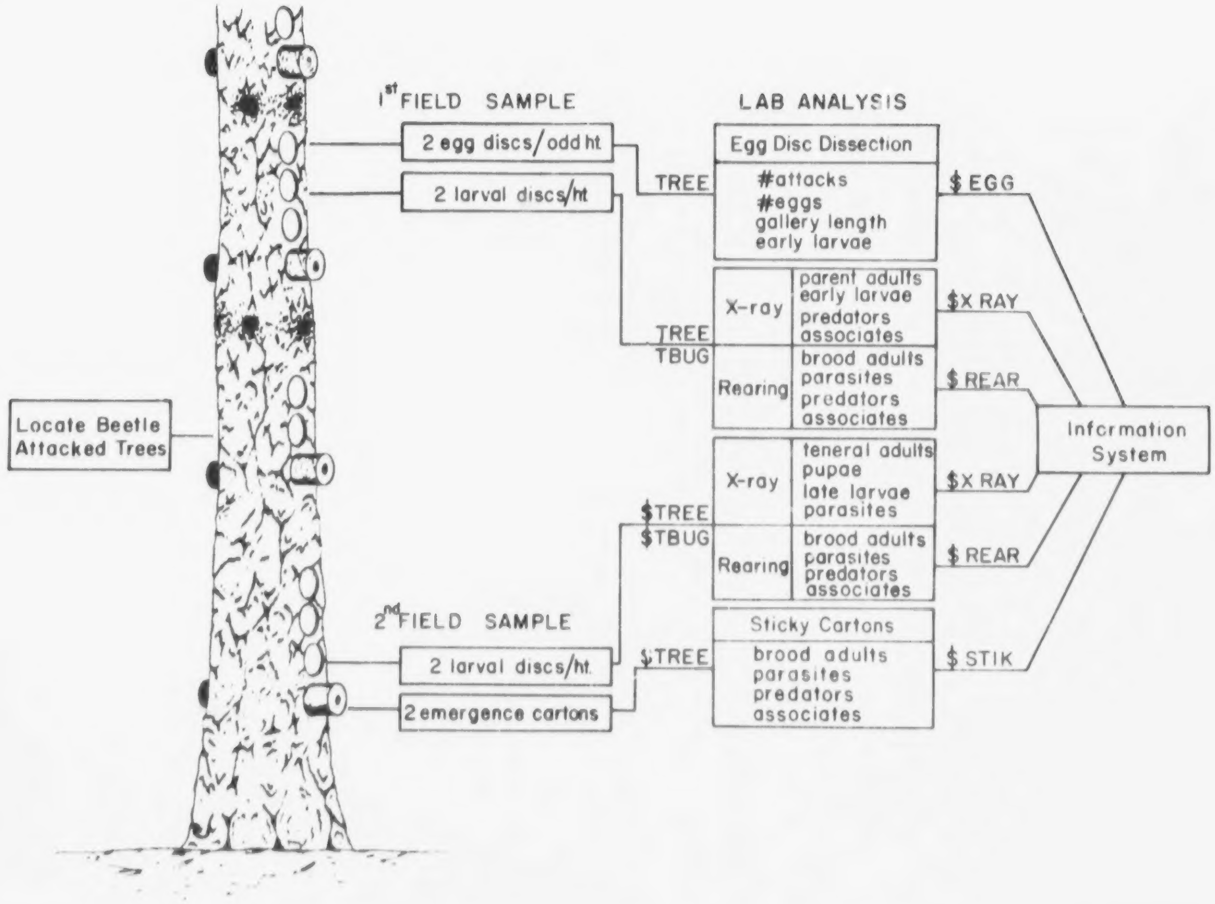
1st FIELD SAMPLE
2 egg discs/odd ht.
2 larval discs/ht.
2nd FIELD SAMPLE
2 larval discs/ht.
2 emergence cartons
Locate Beetle Attacked Trees
TREE
TREE
TBUG
$TREE
$TBUG
$TREE
LAB ANALYSIS
Egg Disc Dissection
#attacks
#eggs
gallery length
early larvae
X-ray
parent adults
early larvae
predators
associates
Rearing
brood adults
parasites
predators
associates
X-ray
teneral adults
pupae
late larvae
parasites
Rearing
brood adults
parasites
predators
associates
Sticky Cartons
brood adults
parasites
predators
associates
$ EGG
$X RAY
$ REAR
$X RAY
$ REAR
$ STIK
Information System

Figure 24. Graphic summary of the population sampling procedures used for the western pine beetle showing datasets and the type of information included for the San Bernardino study.

TABLE 21. HEIGHT, DIAMETER, AND LENGTH OF INFESTATION FOR WESTERN PINE BEETLE SAMPLE TREES SAN BERNARDINO NATIONAL FOREST, 1973-1976.

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest.		Bottom infest.		Lowest sample (m)	Highest sample (m)
				Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)		
1	73-1	18.3	34.4	16.5	15.9	1.5	34.4	1.5	15.0
2	73-1	22.9	44.9	13.5	29.6	1.5	44.9	1.5	13.5
3	73-1	19.2	41.7	13.5	23.2	.5	45.8	1.5	13.5
4	73-1	28.0	50.9	15.5	32.8	.5	57.3	1.5	15.0
5	73-1	29.0	--	19.5	31.8	3.0	--	1.5	19.5
6	73-1	25.9	34.4	13.5	23.9	.5	33.7	1.5	12.0
7	73-1	43.9	87.9	34.5	23.9	.6	90.7	1.5	34.5
8	73-1	29.9	52.5	22.0	15.9	.1	62.4	1.5	21.0
9	73-1	13.7	48.4	12.0	1.0	.4	53.8	1.5	10.5
10	73-1	19.5	36.0	12.0	22.6	.5	39.5	1.5	12.0
11	73-1	20.7	31.5	15.0	18.1	.2	34.4	1.5	15.0
12	73-1	17.1	28.0	12.0	16.9	.6	29.9	1.5	12.0
13	73-2	18.0	29.6	10.8	17.2	.4	32.2	1.5	10.5
14	73-2	16.5	23.2	11.5	15.0	.3	27.7	1.5	10.5

(continued)

TABLE 21. (continued)

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest. Ht. (m)	Top infest. Diam. (cm)	Bottom infest. Ht. (m)	Bottom infest. Diam. (cm)	Lowest sample (m)	Highest sample (m)
15	73-2	24.0	53.8	16.8	23.9	.5	60.8	1.5	15.0
16	73-2	17.7	26.4	12.0	12.4	.1	38.2	1.5	12.0
17	73-2	27.5	56.0	22.7	25.8	.2	60.5	1.5	22.5
18	73-2	18.7	28.0	10.2	21.0	.1	34.7	1.5	9.0
19	73-2	34.0	76.4	28.0	27.1	.2	76.4	1.5	19.5
20	73-2	23.0	30.6	13.1	19.7	.4	32.2	1.5	12.0
21	73-2	22.0	33.4	15.0	22.3	.3	43.3	1.5	9.0
22	73-2	25.0	46.2	18.2	19.7	3.0	58.9	1.5	16.5
23	73-2	20.0	26.4	10.0	19.1	.4	32.5	1.5	9.0
24	73-2	25.5	36.3	14.2	21.7	.5	39.5	1.5	7.5
525	74-1	22.8	69.7	15.0	51.6	.5	75.4	1.5	10.5
526	74-1	16.0	39.2	10.9	24.2	0.0	43.6	1.5	10.5
527	74-1	--	73.2	27.0	27.1	0.0	87.5	1.5	27.0
528	74-1	30.0	--	24.0	45.8	--	--	1.5	24.0

(continued)

TABLE 21.(continued)

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest.		Bottom infest.		Lowest sample (m)	Highest sample (m)
				Ht. (m)	Diam. (cm)	Ht. (m)	Diam. (cm)		
529	74-1	16.2	30.6	13.0	15.9	.4	35.0	1.5	12.0
530	74-1	25.0	60.5	25.0	--	0.0	65.3	1.5	18.0
531	74-1	22.0	94.5	21.0	--	--	93.0	1.5	21.0
532	74-1	30.2	67.8	23.6	29.3	.1	82.4	1.5	22.5
533	74-1	14.4	71.6	14.4	55.7	.7	74.8	1.5	13.5
534	74-1	19.2	51.6	16.8	21.0	0.0	64.0	1.5	16.5
535	74-1	28.4	96.1	16.5	71.0	.3	110.8	1.5	16.5
536	74-1	25.0	48.4	19.8	19.1	.9	50.0	1.5	19.5
537	74-1	26.0	50.0	22.0	16.6	.8	49.3	1.5	21.0
538	74-2	13.7	30.2	10.0	21.7	0.0	33.7	1.5	9.0
539	74-2	12.8	25.2	6.0	19.4	.2	29.9	1.5	6.0
540	74-2	13.7	53.5	11.0	39.2	0.0	57.9	1.5	10.5
541	74-2	28.9	69.1	22.5	36.9	.4	78.3	1.5	19.5
542	74-2	16.3	79.3	13.8	43.9	0.0	88.5	1.5	13.5

(continued)

TABLE 21.(continued)

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest. Ht. (m)	Top infest. Diam. (cm)	Bottom infest. Ht. (m)	Bottom infest. Diam. (cm)	Lowest sample (m)	Highest sample (m)
543	74-2	26.8	90.7	18.0	63.7	.3	95.8	1.5	18.0
544	74-2	22.9	47.1	18.5	23.9	0.0	57.6	1.5	18.0
546	74-2	--	40.4	16.0	18.1	1.5	38.5	1.5	15.0
547	74-2	20.0	38.2	19.0	18.5	0.0	46.2	1.5	18.0
548	74-2	25.0	43.6	18.3	25.2	.5	50.0	1.5	18.0
549	74-2	22.6	36.3	17.0	17.2	0.0	43.6	1.5	16.5
550	74-2	19.0	54.8	12.3	30.2	2.0	53.8	1.5	12.0
551	74-2	27.0	63.0	15.0	41.7	.3	68.1	1.5	13.5
552	75-1	18.0	42.0	10.8	25.8	.1	44.6	1.5	10.5
553	75-1	21.3	45.8	15.2	21.0	1.5	45.8	1.5	15.0
554	75-1	15.6	39.5	11.2	21.7	.3	47.8	1.5	10.5
555	75-1	20.1	65.3	14.5	34.7	3.0	61.1	3.0	13.5
556	75-1	21.9	52.8	12.0	24.2	.1	65.9	1.5	12.0
557	75-1	12.5	32.8	9.0	17.8	.5	38.2	1.5	9.0

(continued)

TABLE 21. (continued)

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest. Ht. (m)	Top infest. Diam. (cm)	Bottom infest. Ht. (m)	Bottom infest. Diam. (cm)	Lowest sample (m)	Highest sample (m)
558	75-2	10.1	48.4	8.8	24.5	0.0	54.1	1.5	7.5
559	75-2	20.4	36.9	15.6	17.2	0.0	44.2	1.5	15.0
560	75-2	25.6	67.5	15.0	33.1	0.0	77.7	1.5	15.0
561	75-2	29.3	62.1	20.5	25.8	0.0	63.7	1.5	19.5
562	75-2	33.8	75.4	18.5	53.2	0.0	84.7	1.5	18.0
563	75-2	--	--	--	--	--	--	1.5	19.5
564	76-1	31.7	74.5	27.5	36.0	1.0	--	1.5	27.0
565	76-1	28.0	37.6	19.0	25.2	.4	42.0	1.5	18.0
566	76-1	32.6	111.7	16.5	79.9	.3	121.0	1.5	16.5
567	76-1	16.2	38.8	11.6	18.1	.1	40.4	1.5	10.5
568	76-1	29.9	52.5	16.9	30.6	0.0	65.9	1.5	16.5
569	76-1	38.4	95.2	16.2	66.8	0.0	111.4	7.5	15.0
570	76-2	25.6	71.0	16.5	48.1	.2	78.3	1.5	16.5
571	76-2	20.7	44.9	17.2	22.6	.1	54.8	1.5	16.5

(continued)

TABLE 21. (continued)

Tree No.	Yr.-Gen.	Tree Ht. (m)	DBH (cm)	Top infest. Ht. (m)	Top infest. Diam. (cm)	Bottom infest. Ht. (m)	Bottom infest. Diam. (cm)	Lowest sample (m)	Highest sample (m)
572	76-2	18.9	41.4	11.2	22.9	1.2	43.6	1.5	10.5
573	76-2	32.3	83.1	23.1	49.0	3.0	80.5	6.0	22.5
574	76-2	18.6	92.0	13.5	71.9	.5	96.8	1.5	13.5
575	76-2	27.7	77.4	24.8	25.8	1.3	78.6	1.5	24.0

TABLE 22. WESTERN PINE BEETLE INFESTED PONDEROSA PINES THAT WERE SAMPLED BETWEEN 1973 AND 1976 RANKED BY OXIDANT DAMAGE.

D. brevicomis generation	Damage class							
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36+
1973-1				2	2	5	2	1
1973-2		3	4	3				2
1974-1	1	3	5	1	3			
1974-2	3	4	3			2		
1975-1		2	2		2			
1975-2		2		2			1	1
1976-1		2		1	1	1		1
1976-2		3		1		1	1	
Years combined	1	7	7	4	8	6	2	2
	3	12	7	6	0	3	2	3
Generations combined	4	19	14	10	8	9	4	5

TABLE 23. WESTERN PINE BEETLE MEAN EGG DISSECTION VARIABLES BY YEAR AND GENERATION FOR WHOLE PONDEROSA PINES, SAN BERNARDINO NATIONAL FOREST, 1973-1976.

	Year Gen.	1973	1974	1975	1976	4 yr mean	Sierra Nevada Blodgett Forest 1967-1970 mean	Miller & Keen 1960
Attacks per dm^2	1	2.88	2.27	2.89	1.32	2.34	1.61	1.25
	2	0.93	0.99	1.48	1.04	1.20	1.56	
Gallery length cm/dm^2	1	79.3	71.8	58.7	60.2	67.5	52.8	
	2	41.7	36.5	46.5	39.3	41.0	45.8	
Total eggs per dm^2	1	71.1	54.7	70.9	86.8	70.9	74.5	69.8
	2	41.2	47.4	63.8	64.8	54.3	78.8	
1st instar larvae per dm^2	1	59.4	45.7	53.5	68.9	56.9	47.3	
	2	30.4	34.2	51.8	49.5	41.5	56.3	
Eggs per cm. of gallery	1	0.90	0.76	1.24	1.41	1.08	1.42	1.65
	2	0.97	1.31	1.35	1.56	1.30	1.69	
Average tree smog rating	1	28.5	14.6	13.8	19.8	19.2		
	2	17.3	11.2	19.3	17.7	16.4		

TABLE 24. VARIABLES CALCULATED FROM WESTERN PINE BEETLE EGG DISC SAMPLE DISSECTION BY GENERATION FROM 1973 TO 1976. SAN BERNARDINO NATIONAL FOREST.

	Gen.	1973	1974	1975	1976	4 Year Mean
Eggs per attack	1	25.0	28.3	47.8	70.8	43.0
	2	45.4	66.0	56.7	75.8	61.0
Gallery length per attach	1	28.2	36.1	38.2	49.2	37.9
	2	48.3	51.6	41.0	47.0	47.0
1st instar larvae per attack	1	20.9	23.4	33.5	57.0	33.7
	2	32.7	47.6	44.8	57.8	45.7
Average tree smog rating	1	28.5	14.6	13.8	19.1	19.2
	2	17.3	11.2	19.3	17.7	16.4

TABLE 25. CORRELATION OF WESTERN PINE EGG DISC DISSECTION VARIABLES WITH YEAR, GENERATION AND TREE OXIDANT RATINGS SAN BERNARDINO NATIONAL FOREST, 1973-1976.

	Generation	Year	Tree Smog Rating
Attacks/dm^2	(-) .05	NS	.05
Gallery length cm/dm^2	(-) .01	NS	.05
Eggs.dm^2	(-) NS	.05	.01
1st instar larvae/dm^2	(-) .01	NS	.05
Eggs/cm. gallery L.	.01	.05	NS
Gallery length/attack	.05	NS	(-) .05
Eggs/attack	.05	.05	NS
1st larvae/attack	.05	.05	NS

Notes: NS = Not significant at 5% level or better.
(-) = Negative correlation.

TABLE 26. MEANS BY GENERATIONS ON THE LAST SAMPLE DATE FOR WESTERN PINE BEETLE BROOD, PARASITES AND PREDATORS FROM X-RAY ANALYSIS OF SAMPLE BARK DISCS. SAN BERNARDINO NATIONAL FOREST, 1973-1976.

		San Bermardino National Forest					Sierra Nevada Blodgett Forest
	Year Gen.	1973	1974	1975	1976	Mean	1966-1970 Mean
Total D.b. brood/dm^2	1	15.1	16.8	26.5	12.4	17.7	13.6
	2	2.18	4.52	3.57	7.42	4.42	6.95
Total parasites	1	0.82	0.59	0.51	0.18	0.52	0.452
	2	0.30	0.59	0.34	0.16	0.35	0.613
Total predators/dm^2	1	3.36	3.07	1.13	1.17	2.18	1.59
	2	0.74	1.25	0.57	0.37	0.73	0.434
Mean tree smog rating	1	28.5	14.0	13.8	19.8	19.0	--
	2	15.4	11.2	19.3	17.7	16.9	--

TABLE 27. SIGNIFICANCE OF MULTIPLE REGRESSION COEFFICIENTS FOR THE LAST SAMPLE DATE OF X-RAY, REARING, AND STICKY CARTONS FOR THE WESTERN PINE BEETLE AND ITS NATURAL ENEMIES, SAN BERNARDINO NATIONAL FOREST, 1973-1976[1].

		Gen.	Year	Smog rating	D.b.	Pred.	Para.
Live D. brevicomis							
	X-ray	.001	.05	.05	---	NS	NS
	Rear	.001	NS	.05	---	NS	NS
	Stik	.01	NS	.05	---	.001	.05
Predators							
	X-ray	.001	.001	NS	NS	---	.001
	Rear	.001	.05	NS	.01	---	NS
	Stik	NS	.01	NS	.001	---	NS
Parasites							
	X-ray	.05	NS	NS	.05	.001	---
	Rear	NS	NS	NS	.01	NS	---
	Stik	NS	NS	NS	.01	NS	---

[1] For D.b., the variables of generation, year, and smog rating were analyzed together, without the effect of predators and parasites. The predators and parasites variables were then added to the equation to test their significance.

TABLE 28. MEAN WESTERN PINE BEETLE AND NATURAL ENEMY EMERGENCE BY GENERATION FOR THE LAST SAMPLE DATE OF LABORATORY REARED DISCS, SAN BERNARDINO NATONAL FOREST, 1973 TO THE FIRST GENERATION OF 1975.

	Year Gen.	1973	1974	1975	S.B.N.F. Mean	Blodgett Forest 1966-1970
Western pine	1	8.00	4.82	6.47	6.43	7.12
beetle per dm^2	2	1.19	1.00		1.10	2.99
Predators	1	1.85	1.67	0.523	1.35	2.88
per dm^2	2	0.315	0.237		0.276	0.177
Parasites	1	0.697	0.301	0.400	0.466	0.298
per dm^2	2	0.318	0.235		0.277	0.630
Mean tree	1	28.5	14.9	13.8	18.7	—
smog rating	2	15.2	11.2		13.2	—

TABLE 29. MEAN WESTERN PINE BEETLE AND NATURAL ENEMY EMERGENCE BY GENERATION FOR THE LAST SAMPLE DATE OF STICKY CARTONS (FIELD RESEARCH), SAN BERNARDINO NATIONAL FOREST, 1973 TO THE FOREST GENERATION OF 1976.

	Year Gen.	1973	1974	1975	1976	S.B.N.F. Mean	Blodgett 1966-1970
Western pine	1	3.86	3.30	1.77	1.60	2.63	4.95
beetle per dm^2	2	0.810	0.297	0.763		0.623	1.45
Predators	1	2.11	1.50	0.746	0.759	1.28	0.947
per dm^2	2	0.91	0.459	0.583		0.65	0.733
Parasites	1	2.20	1.33	1.75	0.146	1.36	1.56
per dm^2	2	0.359	0.343	0.358		0.353	0.639
Mean tree	1	30.4	14.0	13.8	19.8	19.5	—
smog rating	2	15.4	11.2	19.3		15.3	—

TABLE 30 RESULTS OF USING TANG'S CALCULATION OF JEFFREY PINE BEETLE DATA: TREE EFFECT.

Quantity Measured	Sample Size	Calculated	ϕ 50 6 trees	ϕ 50 18 trees	ϕ 50 3 trees	Avg. effect	Conf. found
Gallery	100cm^2	1.02	1.7	1.0	2.0	.177	.67
Length	100cm^2	1.14	1.7	1.0	2.0	.166	.41
Density	250cm^2	1.52	1.7	1.0	2.0	.181	.95
	500cm^2	1.91	1.7	1.0	2.0	.170	.99
	1000cm^2	1.82	1.7	1.0	2.0	.128	.99
Attack	100cm^2	.87	1.7	1.0	2.0	.0018	.50
Density	100cm^2	1.28	1.7	1.0	2.0	.0026	.87
	250cm^2	1.78	1.7	1.0	2.0	.0018	.98
	500cm^2	1.78	1.7	1.0	2.0	.0016	.99
	1000cm^2	2.47	1.7	1.0	2.0	.0016	.99

TABLE 31. RESULTS OF USING TANG'S CALCULATIONS ON JEFFREY PINE BEETLE DATA: HEIGHT EFFECT.

Quantity Measured	Sample Size	ϕ Calculated	ϕ 50 3 heights	ϕ 50 6 heights	Conf. found
Gallery	100cm^2	.484	1.4	1.15	.290
Length	100cm^2	.609	1.4	1.15	.42
Density	250cm^2	.611	1.4	1.15	.42
	500cm^2	.442	1.4	1.15	.25
	1000cm^2	.257	1.4	1.15	.093
Attack	100cm^2	.272	1.4	1.15	.10
Density	100cm^2	.272	1.4	1.15	.87
	250cm^2	.365	1.4	1.15	.18
	500cm^2	.424	1.4	1.15	.24
	1000cm^2	.474	1.4	1.15	.28

TABLE 32. RESULTS OF USING VARIOUS TESTS ON ATTACK DENSITY, SAMPLE SIZE OF DATA, TO DETERMINE DIFFERENCES BETWEEN PAIRS OF TREES. VALUES IN ATTACKS/CM^2.

Trees compared	Mean differ with confidence	For mean dif.	Actual mean dif.	Rel. likelihood that mean differ by 0.25 compared by		Means differ by at least
				D	2D	
1.2	.17	.0033	.0003	0.69	.47	
1.3	.98	.0033	.0040	13.0	.71	.0068
1.4	.83	.0035	.0023	2.3	.55	
1.5	.99	.0029	.0043	89.5	.94	.0014
1.6	.95	.00339	.00333	0.81	.21	

D is the measured difference in means.

TABLE 33. PRELIMINARY SUMMARY OF FINAL SMOG DAMAGE RATINGS FOR PINES KILLED BY INSECTS ON ESTABLISHED VEGETATION PLOTS, 1973-1975.

Tree species[+]	Insect species[‡]	Number of trees	Oxidant injury score[*]			
			Mean	SD	SE	Range
PP	D.b.	17	9.9	6.3	1.5	1-21
PP	D.p.	7	10.4	6.3	2.4	6-25
PP	Mixed (D.b. broods + D.p.)	8	11.8	8.6	3.0	1-30
PP	Ips & M.c. (combined)	5	15.2	10.0	4.5	2-32
JP	D.j.	7	11.6	6.7	2.5	3-19
JP	Mixed (D.j. broods + Ips)	4	13.0	8.2	4.1	4-23

[*] All scores given by P. Miller except those from 1973.

[+] PP = ponderosa pine; JP = Jeffrey pine.

[‡] D.b. = *Dendroctonus brevicomis*; D.p. = *D. ponderosa*; D.j. = *D. jeffreyi*; Ips = *Ips* sp; M.c. = *Melanophila californica*.

Within levels

$$\sigma^2_{WL} = \frac{\sum_{k=1}^{6} \sum_{j=1}^{3} \sum_{i=1}^{2} (y_{ijk} - \bar{y}_{ij})^2}{6 \cdot 3 \cdot 2 - 1}$$

Within trees:

$$\sigma^2_{WT} = \frac{\sum_{k=1}^{6} \sum_{j=1}^{3} (\bar{y}_{jk} - \bar{y}_k)^2}{6 \cdot 3 - 1}$$

Between trees:

$$\sigma^2_{BT} = \frac{\sum_{k=1}^{6} (\bar{y}_k - y)^2}{5}$$

in which

y_{ijk} = value of variable for i^{th} bark sample, j^{th} level, k^{th} tree

$\bar{y}_{jk}$ = mean of 2 bark samples at j^{th} level, k^{th} tree

$\bar{y}_k$ = mean of 6 bark samples for k^{th} tree

$\bar{y}$ = mean overall 6 trees

We assume, for a new population to be sampled, if the variances were similar to those of this population, that the variance of an estimate would be

$$\sigma^2 = \frac{{}^{2}_{BT}}{n} + \frac{{}^{2}_{WT}}{3 \cdot n} + \frac{{}^{2}_{WL}}{3 \cdot m \cdot n}$$

in which

n = number of trees

m = number of samples per each of the 3 levels

Costs of sampling were estimated by the following formula

$$C = \$120 + \$123 \times n + C_i nm$$

in which C_i is the cost of cutting and measuring a bark sample of size i, \$123 is the additional cost of measuring each tree and \$120 is the one time set-up cost of measuring each tree and \$120 is the one time set-up cost of sampling. These costs were derived from tallies of the time spent doing the sampling tasks, $C_{100} = \$2.17$, $C_{250} = \$2.77$, $C_{500} = \$4.07$ and $C_{1000} = \$6.10$.

Using the above formulas sampling was simulated for various combinations of numbers of trees, samples per tree and sample sizes. For each combination the corresponding cost was also calculated.

Application of the Tang procedure--During the initial phase of the analysis of the mountain pine beetle and Jeffrey pine data several types of analyses were used. One procedure was found to be particularly valuable and some calculations using data on the Jeffrey pine beetle were used as an illustration of the application of the Tang procedure.

The Tang procedure supplies the probability that an analysis of variance test will find significance for a certain test given an estimate of the size of the effect of the treatment, an estimate of the variance and the confidence desired. By use of this procedure the probability that an analysis of variance calculation would show significance given that the effect is of a certain size can be determined. Thus, use of this test allows one to conclude that if an analysis of variance computation does not show significance, the actual effect was probably less than a given size.

The Tang procedure is as follows: the quantity ϕ is calculated, where ϕ^2 is given by:

$$\phi^2 = \frac{m \sum d_i^2}{k\sigma^2}$$

d is the size of the ith effect
σ^2 is the variance
k is the number of treatments
m is the number of replications of each treatment.

Separate computations are made for each effect in an experiment in which more than one effect is tested. m,k,d,σ, will of course vary between effects.

For a given combination of degrees of freedom, confidence level, and value of $\sigma 2$, the probabilities of finding significance can be found in tables in statistical textbooks. The probabilities are tabulated for ϕ = 2,2.5,2,2.5,3,4,5,6,7,8.

Vegetation Plot Surveys--

Each numbered tree on each of the 19 vegetation plots was examined twice a year, in July and November. The cause of mortality, if due to an insect, was recorded if a tree had died since the previous survey date.

Results and Discussion

Western Pine Beetle--

The size, extent of infestaton, and the location of the top and bottom sample is summarized for each Ponderosa pine sampled from 1973 to 1976 in Table 21. Most of the sample trees fall in the middle size categories of those attacked since the large trees are too difficult to sample. Also, small trees were not sampled as the western pine broods were often mixed with *Ips* spp. All of the sample trees were smog rated using Miller's (1973) scoring system. The distribution of sample trees by smog score is shown in Table 22.

Evidence for the direct or indirect influence of photochemical oxidants on the dynamics of western pine beetle populations is circumstantial. However, it is interesting to compare the San Bernardino populations with other western pine beetle populations. Where possible the various population parameters are compared with data from Blodgett Experimental Forest (Dahlsten *et al*., 1974) where trees are not damaged by photochemical oxidants but are weakened by a root disease, *Verticicladiella wagneri* (Dahlsten and Rowney, 1974). Some comparisons can be made with the data summarized by Miller and Keen (1960) but their information does not separate out generation effects, which are considerable. The Miller and Keen data was collected before smog damage was prevalent in southern California and the data was collected at sites throughout the state.

Egg disk dissection variables--The first samples taken at the beginning of each generation were the egg disks. The mean values by generation for each of the variables sampled is given in Table 23 along with mean values from Blodgett Forest (Dahlsten *et al*., 1974) and Miller and Keen (1960). Evaluation on a tree by tree basis or by height was not done for this analysis. The main objective was to find possible photochemical oxidant effects on the different life stages of the beetle.

Generally the first generation of beetles attacking in a given year emerge from the overwintering brood trees. These beetles set up what is referred to in the text as the first generation. This generation is more discrete in terms of development, it is the most successful and the most abundant. It is conceivable, too, that the condition of the host trees in mid-June to July when the first generation begins may have considerable influence on the success of the generation. The second generation begins from mid-August to September; at this time of year it is dry and warm, and the incidence of photochemical oxidants is at its peak. Stress on the trees would be greatest at this time of year and the beetles may therefore be affected. Note that the mean tree smog rating was usually (3 of 4 years) lower (a lower score means more oxidant damage) in the second generation (Table 23).

Attack densities per square decimeter (dm^2) were much higher in SBNF in the first generation than those previously recorded at Blodgett or by Miller and Keen, Table 23. The second generation was much lower and this could well be the influence of photochemical oxidants on the trees, i.e., it takes fewer beetles to kill the trees because trees are weakened at this time of year. The low attack densities in 1976, generation one at SBNF could have been due to drought conditions or to a declining beetle population. Note the higher densities in 1975, generation two, Table 22. This, too, could be related to moisture conditions. There was a close relationship between the cm of gallery length per dm^2 and attacks and the same relationships hold, Table 23.

The relationship between attacks and total eggs per dm^2 was consistent except at Blodgett. However, there were small outbreaks at Blodgett in 1967 and 1969 which could explain the jump in the number of eggs in generation two. It appears that whenever an outbreak occurs it is preceded by very high densities of generation two in the previous year.

Density of first instar larvae was as to be expected based on the preceding discussion. Egg mortality can be calculated by the difference between total eggs and first instar larvae. The percent egg mortality at SBNF was 19.7 in generation one and 23.6 in generation two. At Blodgett it was 36.5% in generation one and 28.5% for generation two. There is no explanation for these differences except perhaps the influence of natural enemies. This illustrates the importance of developing life tables which are not yet available. Of particular interest is the large difference in egg mortality between the first generation at SBNF and that at Blodgett.

The eggs per cm of gallery length is usually higher in generation two. This is undoubtedly due to competition, and is an inverse relationship between attacks and eggs per cm of gallery length. The calculated variables in Table 24 further demonstrate intraspecific competition.

Since all trees were ranked by oxidant rating it was possible through covariance analysis to analyze for smog as well as generation and year effects, Table 25. From the data in Table 24 it appears that a direct or perhaps indirect effect could be attributed to photochemical oxidants in generation two. Looking at the tree by tree smog rating shows significant differences between high scoring (not damaged) and low scoring (oxidant damaged) trees for most variables. There is a negative correlation for gallery length/attack and this is to be expected and is due to competition as described above, i.e., the lower the smog score, the greater the gallery length as the attack density is lower, Table 24. There are some significant relationships by year and almost all correlations are significant by generation as would be expected by looking at Tables 23 and 24.

X-ray analysis--The second sampling procedure is designed to analyze the density of western pine beetle brood, its parasites and predators, Figure 24. As with the egg variables, generation one is always higher than generation two, Table 26. Generation one at San Bernardino was higher than Blodgett but generation two was lower. The very low densities for the second generation could well be an effect of smog directly or indirectly as described above.

The parasite and predator densities are very low but tend to be higher in SBNF than Blodgett except for the second generation parasites, Table 26. It is interesting and perhaps important that the highest brood density in the second generation at SBNF occurred when both the predators and parasites were the lowest.

Generation, year, and oxidant ratings are significantly different for western pine beetle brood, Table 27. Generation was significant for the predators and parasites but there is no influence of smog at least indirectly as determined by tree oxidant ratings.

Rearing analysis--Each of the x-ray discs was placed into a carton for rearing and the individuals emerging were identified and recorded. Only the data from the last sample date was considered, as it corresponded more closely to actual emergence in the field and could be compared with the sticky carton samples. The rear data has only been analyzed through the first generation of 1975, Table 28. The same trends are shown with this sampling procedure, i.e., generation one emergence was higher for western pine beetle brood, parasites and predators than generation two. Significant effects of tree smog rating are shown only for western pine beetle brood, Table 27. There were significant effects of generation and year on predators but not on parasites.

A possible link between western pine beetle success and smog is the low mean emergence of beetles in the first generation, Table 28. The densities for western pine beetle were higher than Blodgett up to emergence, and then fell below Blodgett. The SBNF second generation emergence was extremely low. Predator emergence in generation one was lower than Blodgett, while generation two was higher; the relationship between parasites was just the opposite. Both parasitoids and predators were more numerous in the first generation, this was true for x-ray and for sticky cartons.

Sticky carton analysis--Analysis of the sticky carton data is complete through the first generation of 1976. Results from this sample procedure show the same trends as the rearing data, Table 29. The differential effects of environment can be seen by comparing the rearing samples with the sticky carton samples. The mean densities for western pine beetle were always higher in the rearing samples than the sticky carton samples. However, parasites and predators were more dense in the sticky cartons except for the first generation predators. The relationships were exactly the same at Blodgett, Tables 28 and 29. This suggests that one method should be used for the bark beetle and another for the natural enemies.

Significant differences are shown for generation and smog rating, but not for years for the western pine beetle. With the natural enemies only year was significant for predators.

While there is only circumstantial evidence for the direct effect of photochemical oxidants on the western pine beetle, there is good evidence of an indirect effect on the brood from each of the four sampling procedures. Smog damaged trees had a depressing effect on western pine beetle populations. The implications of this in the forest community in San Bernardino are that the probability of an outbreak is lessened since it takes fewer beetles to kill diseased trees and fewer beetles are produced in such a system. Also, since it takes more beetles to kill healthier trees, the healthier trees should be relatively safe. The incidence of drought, mechanical injury, root disease, and fire could drastically alter these generalizations for a particular site. It remains to be seen what this means in terms of management in a recreation forest such as the San Bernardino. The only conclusion that can be made now is that attempts to control the western pine beetle are not necessary as this is treating a symptom rather than the cause of the problem.

Mountain Pine Beetle and Jeffrey Pine Beetle--

The associates, parasitoids and predators reared from trees infested by mountain pine beetle or Jeffrey pine beetle have been listed previously (Dahlsten, 1977). In addition Tables giving means by height in the trees and sample size for number of attacks and gallery length for each beetle species have been recorded earlier (Dahlsten, 1977).

A series of analyses was made on several variables (attacks, gallery length, total larvae, emergence, and total pupae) for each beetle species. For all runs, the lowest cost for a fixed variance or the lowest variance for a fixed cost occurred with the 500 or 1000 cm^2 disk sizes. Figure 25 shows a typical relationship for cost of sampling for fixed variances as a function of bark sample size and Figure 26 is similar except that variance is shown as a function of bark sample size for fixed costs. The feasibility of using the larger bark samples are dubious since handling becomes difficult beyond a certain size and consequently more measurement error may be introduced. The implications are, however, that the larger bark sample sizes are most cost effective.

Variance as a function of cost for a fixed bark sample size for various numbers of samples per height are shown in Figure 27. In nearly every case the sampling of more than 2 units per level did not increase cost effectiveness. Even in cases where 3 or more units per height were better the results were nearly as good for 2 as for more sample units per level.

Application of Tang's procedure--Only two of the variables measured for the Jeffrey pine beetle were used to test the application of Tang's

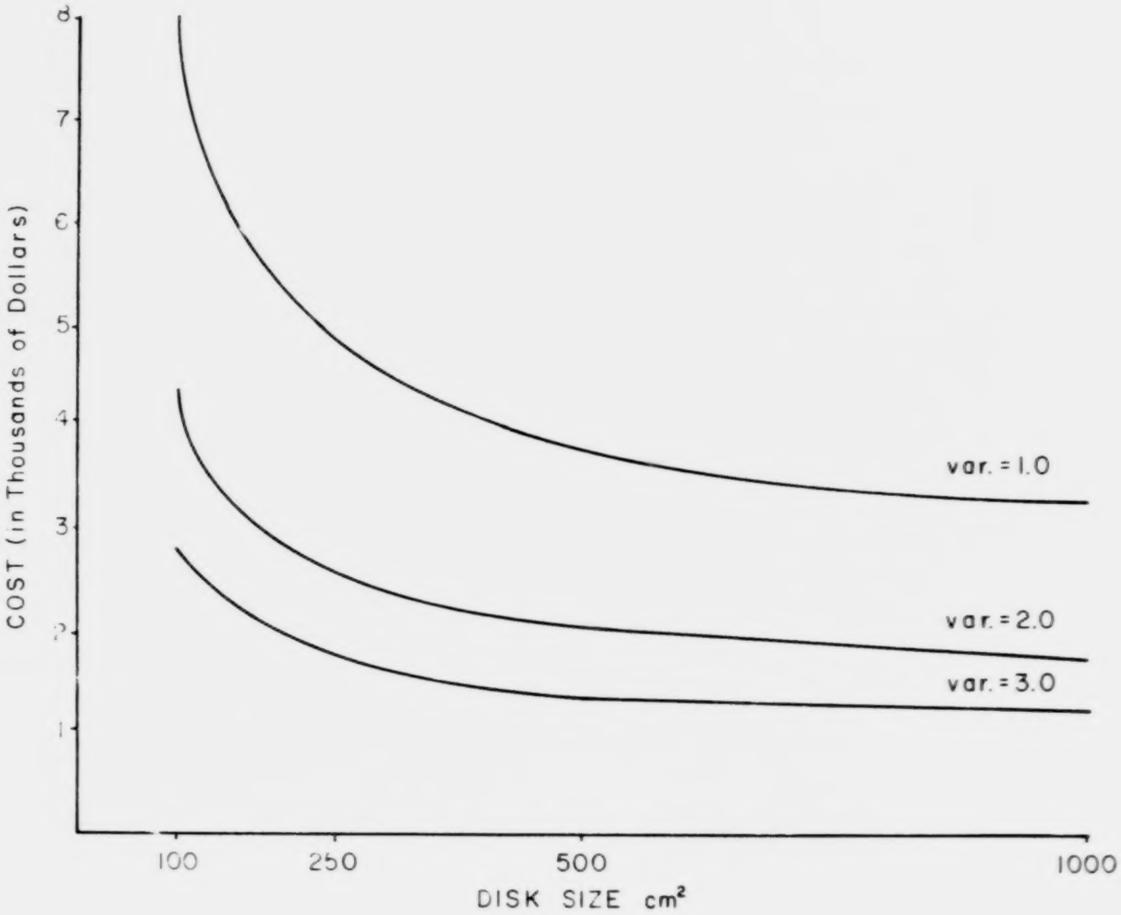

Figure 25. Cost of sampling for fixed variances as a function of bark sample size for total larvae of the Jeffrey pine beetle, 2 bark sample units per height, San Bernardino National Forest, 1974.

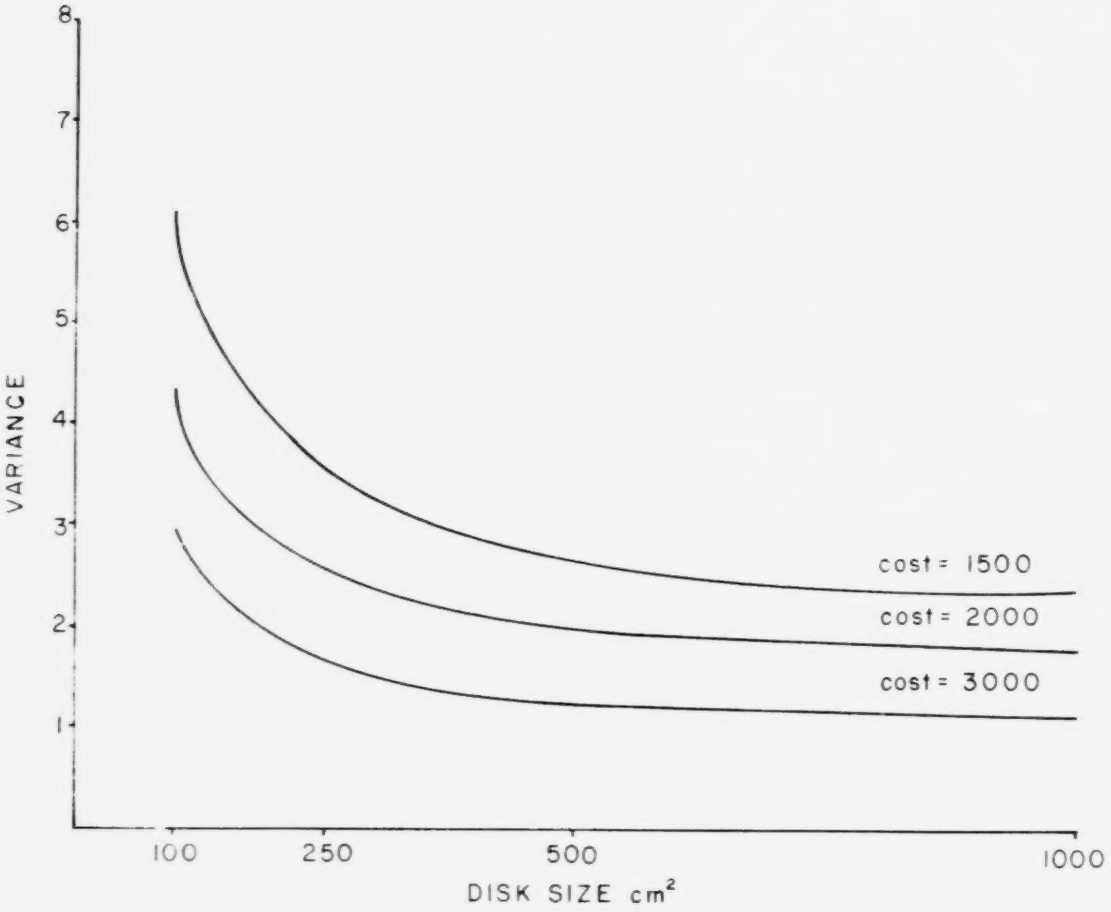

Figure 26. Sample variance as a function of bark sample size for fixed cost for total larvae of the Jeffrey pine beetle, 2 bark sample units per height, San Bernardino National Forest, 1974.

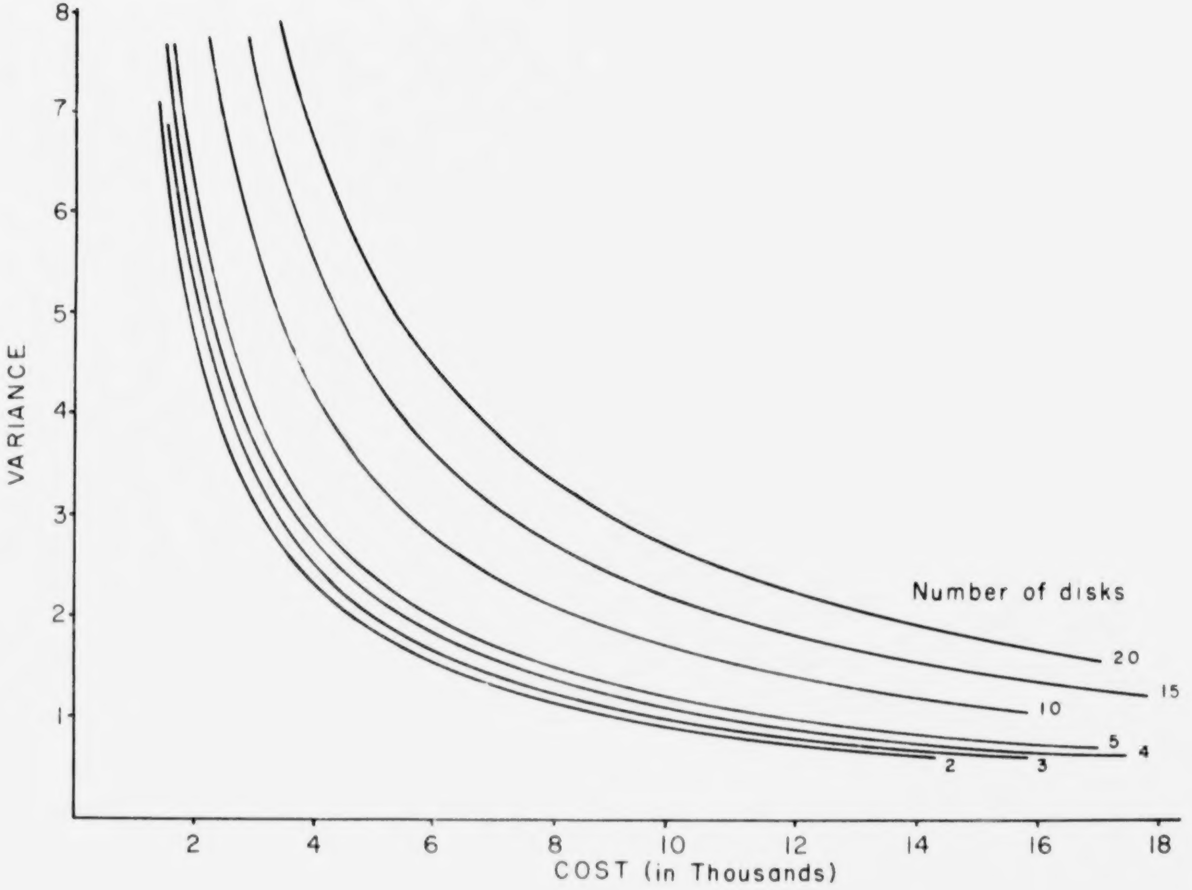

Figure 27. Variance as a function of cost for different numbers of 1000 cm2 samples per height for gallery length of the mountain pine beetle in ponderosa pine, San Bernardino National Forest, 1974.

procedure. The first set of calculations was performed to check the significance of the tree effect on attack density, i.e., to find out if there was significant variation in attack density between trees. For the given conditions (6 trees, 3 heights, 2 measurements at each height which were considered replicates), ϕ_{50}, the value of ϕ needed to have a 50% probability of finding significance is 1.7. If 18 trees were used ϕ_{50} would be approximately 1.0, and for 3 trees about 2.0. The ϕ_{56} are given approximately because the values must be interpolated from graphs. For sample size 1(100 cm^2 disk) ϕ was .871. Hence using sample size 1 there would be little chance of finding significance even if 18 trees were used. On the other hand for sample size 5(1000 cm2 rectangle) ϕ was 2.47. Thus using sample size 5 there was an excellent chance of finding a significant effect with 6 or even with 3 trees. The reason for the difference is that sample size 1 is much smaller, so that the fluctuations are a bigger percentage of the actual measured values. Hence the ratio of the between group to the within group variance is smaller, and more measurements are needed to establish significance.

Generalizations can be made from this example to construct a procedure for using Tang **calculations** in planning sampling schemes. Suppose there is a desire to determine if there is an effect due to treatment of at least a certain size (on the average). Then ϕ_{50} should be calculated for several plausible experimental designs, using values of σ^2 estimated from previous experiments. Actually it might be preferable to calculate $_{85}$ or $_{95}$. When the measurements are made or relevant calculations performed the significance test will show (with appropriate confidence) whether or not the effect of the treatment is greater than a predetermined size.

Table 30 shows the results of calculations for attack density and gallery length density for the tree effect. Table 31 presents results on the same data for the height effect, i.e., the significance of being above, below, or at the center of the infestation.

It can be easily seen from the tables that the chance of finding an effect from a given number of trees generally increases with the sample size. Moreover, in cases where the Tang calculation predicted a high probability of finding significance, the confidence found was generally high. The number in the "confidence found" column is 1 minus the probability of obtaining at random the F value actually found.

Some additional tests were performed on this data. For selected pairs of trees the t test was used to determine the significance of the differences in attack density between trees. The t test is a special case of the analysis of variance test in which there are only two treatments, e.g., one degree of freedom in the numerator. The calculations below are presented merely to illustrate the techniques on several pairs of data sets. Multiple comparisons should not be made with a test on several samples. This is because if there are many samples it is likely that some pairs will have what appear to be significant differences, even if there is no effect of treatment. In such cases an analysis of variance or multiple comparison test should be used.

In addition to the basic t test the following calculations were performed to add information to that supplied by the t test:

1. Difference in population means that would be just large enough to give a significant difference (95% confidence level) was computed and compared to the actual difference in means.

2. If the means differed significantly, then a minimum difference value, M was calculated. It can be said with confidence (95% confidence level) that the means differ by at least M.

3. A calculation was made to find the ratio of the likelihood that, given the observed results, the observed means differ by the measured mean, to the likelihood that the means were the same. In addition, the ratio of the likelihood that the observed means differ by twice the measured mean to the likelihood that they differ by 9 was computed. In the formula for t(equation 1) for the difference of the two populations the appropriate difference was substituted and the differential probablity computed from equation 2, the probability density function for the t variable.

$$(1) \quad t = \frac{\overline{X}-\overline{Y}}{s \, \frac{2}{n}}$$

$\overline{X}$ is the mean for the first population

$\overline{Y}$ is the mean for the second population

s is the estimate of the variance

n is the number of degrees of freedom in each population

$$(2) \quad f(u) = \text{const.} \, (1 + u^2) = \frac{1}{2}f + 1$$

This test can provide a lot more information additional to that in a significance test because it can provide confidence levels on the differences in the means. It can give the relative likelihood that the population means actually differ by any combination of values. If it is found that the means are about as likely to differ by 0 as by the measured means, then the two populations are likely to be the same. If, on the other hand, it is twenty times as likely that the populations differ by the measured mean as by 0, it can be concluded that they are significantly different and also have an idea of the size of the difference.

Table 32 shows some of the results of these calculations. These are for comparisons of various trees for attack density using sample size 4(500 cm^2 rectangle).

Vegetation Plot Surveys--

The results of the vegetation plot surveys through 1975 (Table 33) show that the western pine beetle and the Jeffrey pine beetle were the two most important species in terms of pine mortality. A more complete analysis of the cause of tree mortality on the San Bernardino National Forest is currently in progress (McBride et al., 1977). There is no indication as yet that the smaller vegetation plot survey is representative of the mortality occurring on the San Bernardino National Forest.

EFFECTS OF PHOTOCHEMICAL AIR POLLUTION ON THE EPIDEMIOLOGY OF FOREST TREE PATHOGENS

Introduction

Since the last report, several studies that were in progress have been completed and others initiated during the period 1976-1977 have also been completed. The results of these studies are summarized as follows.

Susceptibility of Roots of Mature Trees--

All live tree root inoculations have been completed. Data (Table 34) for ponderosa pine indicate differences in susceptibility to infection among trees from various air pollution damage categories. Roots from trees showing very severe to severe damage were much more susceptible to proximal infection by *F. annosus* than roots from trees with slight air pollution injury. The term proximal infection is used to indicate that the portion of root between the point of inoculation and the main stem of the tree was invaded by the organism. Distal infection or colonization refers to fungal invasion toward the root tip from point of inoculation.

When distal and proximal infection are considered together, no clear differnces among air pollution damage classes emerge. Results for jeffrey pine do not provide enough basis for air pollution damage comparisons because of the absence of severely injured trees in the sample.

Colonization results for inoculated roots are presented in Table 35. For ponderosa pine, data indicate definite differences in proximal colonization rate in roots from trees showing various levels of air pollution damage. The trend is like that described for infection; i.e., roots from trees severely damaged were more susceptible to colonization by the pathogen. Distal colonization rates show no distinct air pollution related trends.

Regression lines for comparisons between oxidant injury scores and rates of proximal colonization are shown in Figure 23. For both ponderosa pine inoculation trials, relationships between these two variables were statistically significant (P = 0.01).

Greater infection and more rapid colonization of roots by *F. annosus* in severely injured trees could have significant effects on disease epidemiology in affected stands. In such stands, greater tree mortality in shorter time periods could be expected.

Stump Inoculation Studies--

Studies described in the previous progress report were completed.

TABLE 34. INFECTION OF INOCULATED PINE ROOTS WITH FOMES ANNOSUS IN RELATION TO THE SEVERITY OF AIR POLLUTION INJURY.

Site	Species[a]	Air Pollution Damage	No. Roots Inoc.	Root Infection A[b]	%	B[c]	%
Snow Valley	JP	Moderate	12	5	41.7	0	0
		Slight-No Injury	12	7	58.3	4	33.3
Holcomb Valley	JP	Slight-No Injury	19	10	52.6	3	15.8
Breezy Point	PP	Very Severe-Severe	16	7	43.7	5	31.3
		Moderate	8	5	62.5	0	0
		Slight-Very Slight	16	7	43.7	1	6.3
Camp Paivika	PP	Very Severe-Severe	22	15	68.2	15	68.2
		Moderate	17	6	35.3	5	29.4
		Slight	10	5	50.0	1	10.0

[a] JP = Jeffrey pine; PP = ponderosa pine

[b] No. of roots showing proximal and/or distal infection from the point of inoculation

[c] No. of roots showing proximal infection from the point of inoculation

TABLE 35. COLONIZATION OF INOCULATED PINE ROOTS BY FOMES ANNOSUS IN RELATION TO THE SEVERITY OF AIR POLLUTION INJURY.

Site	Species[a]	Air Pollution Damage	Distal Colonization[b]	Proximal Colonization[b]
Snow Valley	JP	Moderate	14.7	0
		Slight-No Injury	17.4	3.1
Holcomb Valley	JP	Slight-No Injury	27.4	0.3
Breezy Point	PP	Very Severe-Severe	11.3	5.6
		Moderate	20.5	0
		Slight-Vey Slight	10.4	0.05
Camp Paivika	PP	Very Severe-Severe	9.4	2.0
		Moderate	6.1	0.7
		Slight	6.4	0.07

[a] JP = Jeffrey pine; PP = ponderosa pine

[b] mm/month

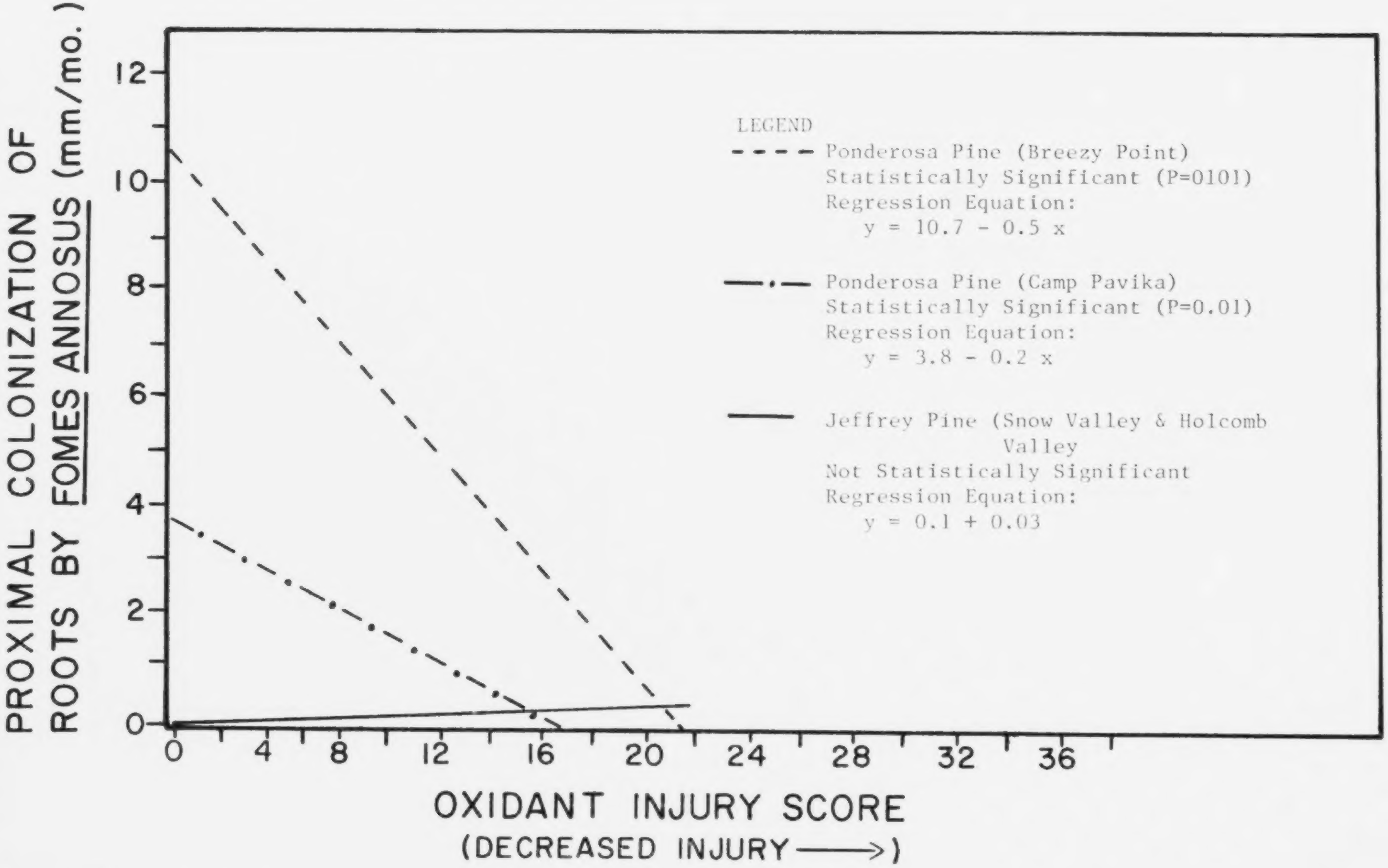

Figure 28. Relationships between oxidant air pollution injury and proximal colonization of inoculated pine roots by Fomes annosus.

Also, two additional twenty-stump trials were done (one for Jeffrey pine and one for ponderosa pine). Table 36 summarizes characteristics of stumps which were inoculated.

All inoculated stumps became infected with F. annosus. Stumps from trees severely injured by air pollution were about twice as susceptible to F. annosus, based upon percent of surface area colonized (Table 37), as stumps from trees showing slight or no injury. Surface colonization percentages were similar for ponderosa pine at Barton Flats and Jeffrey pine at Amphitheatre. Much greater surface colonization occurred in ponderosa pine stumps at Camp Paivika. This may be explained in part by the different F. annosus isolate used there.

Regression analyses comparing oxidant injury score with surface colonization by F. annosus were completed. For ponderosa and Jeffrey pine, as the oxidant injury score decreased (corresponding to greater air pollution injury) stump surface colonization increased. This correlation was significant for ponderosa pine at both sites tested (Barton Flats P=0.025; Camp Paivika P=0.01). The correlation for Jeffrey pine at Amphitheatre was significant only at the 0.25 level.

Table 38 presents F. annosus colonization rate and extension in stumps at least six months after inoculation. The pathogen colonized stumps of ponderosa pine trees severely injured by air pollution at a 30% greater rate than stumps from trees showing slight or no injury. A 50% rate differential was found in colonization of jeffrey pine stumps. Stump colonization rates at Barton Flats were less than at the other two sites. This is probably caused, in part, by season of inoculation and isolate differences from other trials.

Regression analyses, comparing downward colonization and colonization rates with oxidant injury score were done. As oxidant injury score decreased, indicating greater injury colonization rate and downward fungal extension increased. For both dependent variables, relationships were statistically significant at the .05 level for ponderosa pine at CP and Jeffrey pine at the Amphitheatre. They were significant for ponderosa pine at BF only at the 0.25 level.

The stump volume colonized by F. annosus six (BF and Amphitheatre) and ten (CP) months after inoculation are summarized in Table 39. At BF, stumps from trees severely injured by air pollution had twice as much volume colonized by F. annosus as stumps from trees slightly injured. Amphitheatre and CP had nearly a 3:1 volume colonization ratio of stumps from severely injured trees to stumps from slightly injured trees.

Regression analysis showed that the volume of stump colonized increased with decreasing oxidant injury scores. This correlation was statistically significant at the .01 level for ponderosa pine at CP, but not at BF (P = .25). The correlation was significant at the 0.10 level for Jeffrey pine (Amphitheatre).

TABLE 36. NUMBER OF PINE STUMPS INOCULATED WITH FOMES ANNOSUS BY SITE AND SPECIES.

Pollution Damage*	Barton Flats (Ponderosa Pine)	Amphitheatre (Jeffrey Pine)	Camp Paivika (Ponderosa Pine)
Very Severe	5	1	5
Severe	5	4	5
Moderate	0	5	0
Slight	3	2	9
Very Slight	3	7	1
No Injury	4	1	0
Total	20	20	20
Ave. DBH (dm)	1.54	2.27	2.53
Ave. Hgt.(m)	8.64	11.81	10.60

*Equivalent Numerical Ratings:

Very Severe:	1-8
Severe:	9-14
Moderate:	15-21
Slight:	22-28
Very Slight:	29-35
No Injury:	36+

TABLE 37. RELATIONSHIP BETWEEN THE SURFACE COLONIZATION OF INOCULATED PINE STUMPS BY *FOMES ANNOSUS* AND THE SEVERITY OF AIR POLLUTION INJURY.

Site[1]	Species[2]	*F..annosus* Isolate	Air Pollution Damage	% Surface Colonization[3]	Ratio
BF	PP	SV1	Very Severe-Severe	36.9	2.10
BF	PP	SV1	Slight-No Injury	17.6	
AMP	JP	SV1	Very Severe-Moderate	33.1	2.09
AMP	JP	SV1	Slight-No Injury	15.8	
CP	PP	JL1	Very Severe-Severe	86.0	1.87
CP	PP	JL1	Slight-Very Slight	45.9	

[1] BF = Barton Flats; AMP = Amphitheatre; CP = Camp Paivika

[2] PP = ponderosa pine; JP = Jeffrey pine

[3] One month after inoculation

TABLE 38. DOWNWARD COLONIZATION AND COLONIZATION OF *FOMES ANNOSUS* IN INOCULATED PINE STUMP RELATIVE TO AIR POLLUTION INJURY.

Site[1]	Species[2]	Air Pollution Damage	Downward Colonization[3]	Colonization Rate[4]	Ratio
BF	PP	Very Severe-Severe	122.8	20.5	1.30
BF	PP	Slight-No Injury	94.5	15.8	
AMP	JP	Very Severe-Moderate	306.1	51.0	1.49
AMP	JP	Slight-No Injury	205.6	34.2	
CP	PP	Very Severe-Severe	407.3	40.7	1.31
CP	PP	Slight-Very Slight	311.4	31.1	

[1] BF = Barton Flats; AMP = Amphitheatre; CP = Camp Paivika

[2] PP = ponderosa pine; JP = Jeffrey pine

[3] Six months after inoculation for Barton Flats and Amphitheatre; ten months after inoculation for Camp Paivika (Given in mm)

[4] Given in mm/month

TABLE 39. VOLUME OF INOCULATED STUMPS COLONIZED BY *FOMES ANNOSUS* IN RELATION TO AIR POLLUTION INJURY.

Site[1]	Species[2]	Air Pollution Damage	% Volume Colonized[3]	Ratio
BF	PP	Very Severe-Severe	15.6	1.95
BF	PP	Slight-No Injury	8.0	
AMP	JP	Very Severe-Moderate	28.1	3.19
AMP	JP	Slight-No Injury	8.8	
CP	PP	Very Severe-Severe	61.0	3.10
CP	PP	Slight-Very Slight	19.7	

---

[1] BF = Barton Flats; AMP = Amphitheatre; CP = Camp Paivika

[2] PP = ponderosa pine; JP = Jeffrey pine

[3] For Barton Flats the figures indicate % volume colonized in the top 130 mm of each stump at the end of six months. For Amphitheatre and Camp Paivika, the figures indicate colonization for the entire height of each stump at the end of six and ten months respectively.

Effects on Growth, Spore Production, Spore Germination, and Adaptability of Fomes Annosus--

Photochemical air pollutants probably influence F. annosus directly during portions of the disease cycle, such as during spore production, dispersal and germination. Penetration of stump surfaces by the fungus may also be affected.

Direct effects of ozone on characteristic behavior of F. annosus in culture and during wood disk colonization were investigated. Growth chambers were used to control other environmental factors. Five characteristics of F. annosus potentially affected by ozone were studied: linear growth, conidial production, conidial germination, colonization of freshly-cut pine discs and adaptability over successive generations.

Four San Bernardino Mountain isolates were used to study ozone effects on F. annosus linear growth rate and conidial production. Ten-day-old cultures were fumigated at four ozone concentrations (0.05 - 0.45 ppm = 98 - 88z ug/m^3) for three days. Growth and conidial production were determined after fumigation. As ozone dosage increased, growth rate and conidial production decreased (Table 40). Significant differences in growth rate between the controls and ozone-exposed culture occurred for ozone concentrations of 0.10 ppm (196 ug/m^3) or greater. Differences in conidial production occurred at all ozone concentrations.

Experiments were conducted with 2 isolates to ascertain direct ozone effects on conidial germination. Spores on water agar petri plates were fumigated with ozone at three concentrations for various time periods. As ozone dosage increased, percent germination generally decreased, (Tables 41 and 42) with the greatest change at higher ozone levels, such as 0.45 ppm for 4 and 8 hours (4301.7 and 9544.2 ug/m^3/hr).

In another experiment to determine ozone effects on conidial germination and germ tube extension, conidia were fumigated for 12 hours at concentrations of from 0.09 - 0.72 ppm (176.4 - 1411.2 ug/m^3). As ozone dosage increased, germination decreased (at 0.72 ppm, no conidia germinated), average germ tube length decreased, and percentage of germ tubes with branches was less (Table 43).

Two F. annosus isolates were used to evaluate effects of ozone on the colonization of wood discs. Discs inoculated with conidia were fumigated at four concentrations of ozone for seven days. Extent of colonization by F. annosus over the surface of discs were determined after ozone exposure. Colonization of discs exposed to ozone was significantly less than the controls at ozone concentrations of 0.11 ppm (16868.2 ug/m^3/hr) and greater (Table 44).

Two F. annosus isolates were used to investigate adaptability to ozone through a number of successive generations. F. annosus conidia were ozone-fumigated for three successive generations to ascertain whether germination percentages changed after each fumigation. No significant differences in conidial germination occurred during the sequences of ozone

TABLE 40. INFLUENCE OF OZONE ON THE LINEAR GROWTH RATE AND CONIDIAL PRODUCTION OF *FOMES ANNOSUS*.

Isolate	Ozone Conc. (ppm)	Ozone Dosage[1] (ug/m3-hr)	Growth Rate (% of Controls)	Conidial Production (% of Controls)
JL1	0.045	2401.0	77.6[2]	16.3
	0.10	5634.0	10.3	1.2
	0.22	11477.0	12.0	0.0
	0.45	23814.0	7.5	0.0
JP1	0.05	2646.0	75.5[2]	14.6
	0.10	6350.4	19.6	8.3
	0.22	11477.0	11.3	5.9
	0.45	25401.6	4.6	0.0
C1	0.045	2401.0	86.8[2]	10.3
	0.10	6350.4	42.6	8.6
	0.22	13230.0	18.9	3.6
	0.45	23814.0	14.8	0.0
PP1	0.05	2646.0	82.1[2]	34.3
	0.10	5634.0	30.8	28.0
	0.22	13230.0	19.0	7.5
	0.45	25401.6	5.5	0.0

---

[1] Cultures were fumigated 9 hours daily for 3 days (total 27 hours).

[2] Not statistically significant ($P=0.05$) using one-way analysis of variance comparing control and ozone fumigated cultures. All other such comparisons were statistically different.

TABLE 41. INFLUENCE OF OZONE ON CONIDIAL GERMINATION OF *FOMES ANNOSUS* (ISOLATE: JL1).

Ozone Conc. (ppm)	Exposure Time (hr)	Ozone Dosage (ug/m^3-hr)	Control Ave. % Germin.[a]	Control $S_{\bar{x}}$[b]	Ozone Fum. Ave. % Germin.[a]	Ozone Fum. $S_{\bar{x}}$[b]	% of Control	F Value[c]
0.10	1	183.9	90.3AB	2.34	93.4F	1.95	103.4	10.2[d]
0.10	2	396.9	89.6A	3.92	85.4BC	5.60	95.3	3.8[e]
0.22	1	444.7	92.2ABC	2.48	87.1C	3.18	94.5	16.0[d]
0.10	4	749.2	94.6BC	1.90	86.4C	3.13	91.3	50.1[d]
0.45	1	888.0	89.3A	2.79	82.1ABC	4.15	91.9	20.7[d]
0.22	2	931.6	91.7ABC	1.95	85.7C	2.87	93.5	29.9[d]
0.10	8	1573.9	91.1ABC	1.64	83.8ABC	3.85	91.9	29.5[d]
0.22	4	1770.6	93.4BC	2.63	83.5ABC	3.17	89.4	57.7[d]
0.45	2	2058.0	91.5ABC	2.37	79.7AB	1.89	87.1	151.7[d]
0.22	8	4167.5	90.2AB	2.62	78.9A	5.22	87.5	40.1[d]
0.45	4	4301.7	90.1AB	2.13	57.8E	3.12	64.1	730.7[d]
0.45	8	9544.2	88.8A	1.87	29.1D	5.26	32.8	1143.5[d]

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[a] Means followed by the same capital letter are not significantly different (P=0.05) using the Studentized Range Test for Multiple Comparisons.

[b] Standard Deviation

[c] Based on one-way analysis of variance comparing control and ozone fumigation mean germination values:

[d] Statistically Significant (P=0.01)

[e] Not Statistically Significnat

TABLE 42. INFLUENCE OF OZONE ON CONIDIAL GERMINATION OF FOMES ANNOSUS (ISOLATE: PP1).

Ozone Conc. (ppm)	Exposure Time (hr)	Ozone Dosage (ug/m^3-hr)	Control Ave. % Germin.[a]	Control $S_{\bar{x}}$[b]	Ozone Fum. Ave. % Germin.[a]	Ozone Fum. $S_{\bar{x}}$[b]	% of Control	F Value[c]
0.10	1	183.9	91.0B	2.34	94.1G	1.95	103.4	6.6[e]
0.10	2	396.9	91.8B	2.78	80.2EF	4.47	87.4	48.6[d]
0.22	1	444.7	73.1A	3.14	75.7DE	3.31	103.4	3.2[g]
0.10	4	749.2	90.6B	2.07	85.2F	6.68	94.0	6.0[f]
0.45	1	888.0	88.1B	3.41	66.9C	4.01	75.9	161.9[d]
0.22	2	931.6	72.4A	4.06	68.3CD	5.91	94.3	3.3[g]
0.10	8	1573.9	89.4B	1.65	81.9EF	4.72	91.6	22.7[d]
0.22	4	1770.6	72.1A	5.34	55.6B	5.93	77.1	42.7[d]
0.45	2	2058.0	89.6B	2.01	56.6B	2.17	63.2	1266.7[d]
0.22	8	4167.5	71.4A	2.22	40.9A	13.00	57.3	53.5[d]
0.45	4	4301.7	90.2B	1.93	54.3B	2.79	60.2	1118.5[d]
0.45	8	9544.2	88.2B	2.90	35.2A	2.53	39.9	1956.7[d]

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[a] Means followed by the same capital letter are not significantly different (P=0.05) using the Studentized Range Test for Multiple Comparisons.

[b] Standard Deviation

[c] Based on one-way analysis of variance comapring control and ozone fumigation mean germination values:

[d] Statistically Significant (P=0.01)

[e] Statistically Significant (P=0.025)

[f] Statistically Significant (P=0.05)

[g] Not Statistically Significant

TABLE 43. INFLUENCE OF OZONE EXPOSURE ON CONIDIAL GERMINATION AND GERM TUBE EXTENSION OF *FOMES ANNOSUS*.

Isolate	Ozone Conc. (ppm)	Ozone Dosage ($\mu g/m^3$-hr)	Percent Germination[a]	Ave. Germ Tube Length[b] (mm)	$S_{\bar{x}}$[c]	Percent[d] BGT
	0	0	41.8	0.077E	0.051	20.0
	0.09	2205.0	23.5	0.039CD	0.020	7.0
JL1	0.18	4145.4	4.0	0.038CD	0.025	11.2
	0.25	5884.9	2.2	0.022B	0.018	4.0
	0.72	16993.2	0	0A	0	0
	0	0	39.1	0.079E	0.047	13.4
	0.09	2205.0	21.0	0.041D	0.020	2.6
HB11	0.18	4145.4	4.8	0.36CD	0.025	5.6
	0.25	5884.9	3.4	0.029BC	0.026	4.0
	0.72	16993.2	0	0A	0	0

[a] After 12 hours incubation

[b] Mean followed by the same capital letter not significantly different (P=0.05) using the Studentized Range Test for Multiple Comparisons.

[c] Standard Deviation

[d] Percent of germ tubes with branches.

TABLE 44. EFFECTS OF OZONE ON THE COLONIZATION OF PINE DISCS BY *FOMES ANNOSUS*.

Isolate	Ozone Concentration (ppm)	Ozone Dosage (ug/m^3-hr)	Disc Colonization Control[a]	Disc Colonization O_3 Exposed[a]	% of Control	F[b]
JL1	0.06	8736.2	71.1A	75.6C	106.3	2.1
	0.10	12595.0	75.5AB	59.3AB	78.5	10.7[c]
	0.11	16868.2	80.4BC	59.6AB	74.1	29.2[c]
	0.27	31928.4	84.0C	55.0A	65.5	134.6[c]
HB11	0.06	8736.2	79.0ABC	73.8C	93.4	0.5
	0.10	12595.0	77.5ABC	67.9BC	87.6	2.3
	0.11	16868.2	76.2ABC	62.6AB	82.1	35.6[c]
	0.27	31928.4	70.8A	57.0A	80.5	39.8[c]

[a] Given in percent--Means followed by the same capital letter are not significantly different (P=0.05) using Duncan's Multiple Range Comparison Test.

[b] F values based on one-way analysis of variance comparing control and ozone exposed percent colonization values.

[c] Statistically significant (P=0.01).

fumigation (Table 45). Spores selected for their germination ability in an ozone environment did not give rise to colonies which subsequently had spores with improved germinative capabilities.

In summary, ozone influenced certain cultural characteristics of *F. annosus* under growth chamber conditions. Growth rate, sporulation, spore germination and colonization of wood discs were all limited by ozone, with the most dramatic effects occurring at high dosages. No evidence of adaptation by the fungus to an environment with ozone was found. Sensitivity of the fungus to ozone may have little effect on epidemiology under field conditions since the pathogen, because of its occurrence within host tissues and because it commonly sporulates at night and during moist periods, is not often exposed to the gas during its life cycle.

Epidemiological Model

Development of a model to simulate *F. annosus* behavior in a pine ecosystem impacted by photochemical air pollution was a goal of this research. From such a model, prediction of potential disease buildup and future losses might be made.

The model predicts tree mortality expected in stands subjected to high dosages of photochemical air pollution relative to stands not impacted. Experimental data and regression equations were used at various disease cycle stages to quantify air pollution effects. The model predicts that *F. annosus* root disease would be expected to increase at a rate 7 times greater than in a stand with no injury. For example, the model indicates that within 50 years of initial stump infection, 31 times more trees would die from *F. annosus* infection in stands severely injured by air pollution (average rating = 14) than in stands with no injury. This prediction needs verification by further experimentation and/or testing in the field.

Disease Survey

Results of the surveys of 1974 and 1976 on all vegetation plots were keypunched and input to the data management system. A print-out was made of the discrepancies, if any, in disease observation of each tree between the two years. Each discrepancy was screened to determine if:

1) An observational error was made (a highly improbably change indicated this).

2) An incorrect code was recorded for a good observation.

3) An actual change in disease status was observed.

In the case of (1) and (2) a certain number of trees required rechecking in the field. This was done during the early summer of 1977. The list of corrections have not yet been input to the computer data file.

TABLE 45. INFLUENCE OF OZONE ON *FOMES ANNOSUS* CONIDIAL GERMINATION THROUGH SUCCESSIVE GENERATIONS OF EXPOSURE.

Isolate Designation	Ozone Concentration (ppm)	Cumulative Dosage (ug/m^3-hr)	Percentage Germination*		Test
			Controls	O_3 Exposed	
JL1	0.10	2353.	40.0A	27.0A	G1
JL1-1A	0.10	4704.	40.6A	22.4A	G2
JL1-1B	0.10	4704.	40.2A	26.6A	G2
JL1-2A	0.10	7056.	39.0A	27.4A	G3
JL1-2B	0.10	7056.	42.0A	27.8A	G3
HB11	0.10	2353.	39.4A	23.4A	G1
HB11-1A	0.10	4704.	39.2A	24.2A	G2
HB11-1B	0.10	4704.	40.4A	24.8A	G2
HB11-2A	0.10	7056.	36.2A	22.4A	G3
HB11-2B	0.10	7056.	35.6A	25.0A	G3

*Within each category, means followed by the same Capital letter are not significantly different (P=0.05) using Duncan's Multiple Range Comparison Test.

CAUSE AND EXTENT OF TREE MORTALITY

Introduction

Tree mortality is an important regulator of stand composition and density. It also plays a major role in forest succession. The study reported here was initiated in 1976 to determine the cause and extent of tree mortality in the mixed conifer forest of the San Bernardino Mountains. The focus of the study was to identify the major causes of mortality and relate their occurrence to the incidence of oxidant pollutant injury to the forest.

Research Objectives

1. To identify the causes of mortality of the conifer species in the mixed conifer forest of the San Bernardino Mountains.
2. To determine the extent of mortality in these conifer species.
3. To relate mortality to the incidence of air pollution injury to the forest.

Literature Review

The general impact of forest insects, pathogens, and oxidant air pollutants on the forests of the San Bernardino Mountains has been reviewed by Wood (1973) and Miller and McBride (1973). Observations of tree mortality and insect occurrence on the 18 permanent plots established to observe air pollution injury on forest trees in the EPA study have been reported by Miller (1977) and Dahlsten et al (1974). The major insect pests, western pine beetle (*Dendroctonus brevicomis* Le Conte), mountain pine beetle (*D. ponderosae* Hopkins) and Jeffrey pine beetle (*D. jeffreyi* Hopkins), and some aspects of their population dynamics in the San Bernardino Mountains have been discussed in relation to oxidant air pollutants by Dahlsten et al (1977). James et al (1977) has reported several experiments which explored the relationship between the pathogenicity *Fomes annosus* (Fr.) Cke. and oxidant air pollutants.

All of these studies have focused on selected plots within the San Bernardino Mountains which were established in an attempt to determine the extent and cause of tree mortality as well as air pollution injury (McBride, 1974; Dahlsten et al, 1974; Cobb et al, 1974). The plots unfortunately were not large enough to sufficiently measure the extent and cause of tree mortality.

Materials and Methods

The method used to determine the cause and extent of tree mortality was developed by Byler, Hart and Wood (1976). In brief, the method involved the following steps:

1. Random selection of plots, of approximately 285 acres each, to provide a 15% sample of the mixed conifer and yellow pine forest types in the San Bernardino Mountains as defined by the U.S.F.S.
2. Aerial photography of each plot using Ektachrome MS film.
3. Photointerpretation of each plot to identify and locate all dead trees.
4. Ground check of a sample of dead trees reported by photointerpreter. This survey was designed to check the accuracy of the photointerpretation and to determine the cause of tree mortality.
5. Measurement of stand conditions on a sample of the ground check plots to determine stand and site conditions and pests.
6. Calculation of extent of mortality by each pest complex.

Laboratory Analysis Procedure

Verification of the field identification of pathogens was made on cultured samples of root material. This root material was plated on agar and incubated for 14 days under sterile conditions in the laboratory. Identification of fungal species was based on the appearance of fruiting bodies and/or hyphal configurations examined under the microscope.

Results and Discussion

A total of 220 dead trees were inspected during the ground check portion of the study. It is estimated, by projecting this sample to the entire forest, that 11,243 trees died during 1976. An overall summary of the mortality percentages is shown in Table 46.

Specific pest complexes were identified for the major forest species. Only Jeffrey pine and white fir are reported here because an insufficient number of mortality centers for the other species (Table 47). Examination of the data indicate that an overwhelming number of trees have succumbed to the combined attack of disease and forest insects rather than a single pest species. The combined effects of the Jeffrey pine beetle and dwarf mistletoe were the most common cause of mortality in Jeffrey pine while the fir engraver beetle and *Fomes* root and butt rot were most common in white fir.

The correlation between tree mortality and air pollution injury was much lower than anticipated (Table 48). The data collected reflects the distribution of the samples rather than what is believed to be the actual

TABLE 46. TREE MORTALITY BY CAUSES AND SPECIES IN THE SAN BERNARDINO MOUNTAINS IN 1976.

Mortality Cause	Percent of Total Mortality Jeffrey Pine	Combined Jeffrey Pine and White Fir	White Fir
Pathogens and Insects	61	70	78
Insects	34	21	9
Pathogens	1	1	3
Other	4	10	8

TABLE 47. TREE MORTALITY BY PEST COMPLEX AND SPECIES IN THE SAN BERNARDINO MOUNTAINS IN 1976.

Pest Complex	Percent of Total Mortality Jeffrey Pine	Combined Jeffrey Pine and White Fir	White Fir
Root Disease and Insects	26	39	53
Root Disease, Mistletoe and Insects	18*	16	19**
Mistletoe and Insects	22*	15	6
Insects alone	19	14	9
Insects and Mechanical Injury	15	7	0
Pathogens alone	1	1	3
No insect, pathogen, or injury apparent	4	10	8

*Dwarf Mistletoe

**Tree Mistletoe

relationship between air pollution injury and tree mortality. It does not fit the trends observed by Miller (1977) on the 18 permanent plots established to observe air pollution injury. The samples selected for study fell outside of the zone of severe air pollution. Most of the samples were, in fact, in areas of slight oxidant concentration. Subsequent surveys of tree mortality will be stratified in order to obtain samples from zones of high oxidant concentration.

TABLE 48. PERCENT OF MORTALITY CENTERS IN THE MIXED CONIFER AND YELLOW PINE FORESTS IN RELATION TO OXIDANT INJURY.

Oxidant Injury		Percent of Sampled Mortality Centers	
Rating	Class	Mixed Conifer Forest	Yellow Pine Forest
1- 8	very severe	0	0
9-14	severe	1.1	0
15-21	moderate	3.4	7.9
22-28	slight	8.0	7.9
29-35	very slight	20.4	38.6
36+	no visible symptoms	67.1	45.6

EFFECTS OF PHOTOCHEMICAL AIR POLLUTION ON FOREST TREE SEEDLING ESTABLISHMENT

Introduction

The purpose of this subproject is to investigate: (1) the rate of tree seedling establishment in forest stands exposed to different levels of photochemical oxidants; (2) the influences, both direct and indirect, of oxidants on the establishment of ponderosa and Jeffrey pine seedlings; (3) the individual and concurrent joint effects of biotic and physical factors on seedling establishment, and (4) the influence of an oxidant gradient on these biotic and physical factors.

The investigations initiated in the 1976-1977 period included studies (1) to determine the rate of seedling establishment in forest stands along an oxidant gradient; (2) to evaluate the individual and joint effects of vertebrates, arthropods, and pathogens on seeds and seedling establishment; (3) to evaluate the interactions between litter depth and type and the effects of the biotic agents; (4) to determine the relationships between litter decomposing organisms and those organisms causing loss of seeds and seedlings; (5) to further analyze data from studies initiated during the 1975-1976 contract period.

The following is a summary of studies and results obtained during the 1976-1977 period.

Pathogenicity Test of Litter Organisms

This test was designed to determine which fungi isolated from pine litter were pathogenic to pine seeds and seedlings. Seven fungi were tested in the initial study: *Mucor*, *Curvularia*, *Aureobasidium*, *Alternaria*, *Ulocladium*, *Penicillium*, and *Fusarium roseum*.

Summary of Test Procedure--

Inoculum of the seven fungi was grown on a litter substrate in dishes for 12 days; 10 seeds then planted in each plate. The plates were watered and incubated in a cool environment (4.4°C) for 20 days; then they were removed during the day to room temperature (18°C) and returned to the cool environment at night for an additional 57 days. They were watered periodically, and dying seedlings were removed and isolated from the culture dishes. At the conclusion of the study remaining seeds, seedlings, and samples from the surface and subsurface of the litter substrate were isolated from each of the substrate dishes.

Test Results--

A summary of the results for each fungus and the control are given in Table 49. Seed germination was observed to be lower in all inoculated plates than in the controls,.but it was only substantially lower for the _Penicillium_ plates. Although the fungus was not isolated from a high percent of the nongerminated seeds.

The _Alternaria_ plates were observed to have a substantially higher number of diseased seedlings than the control; however, _Alternaria_ was only isolated from about half of the diseased seedlings. The 31.7% diseased controls contained some organisms used in the other plates, indicating some contamination may have occured between plates.

Final conclusions from this experiment will be drawn after a statistical analysis is performed on the data. Initial results indicate that _Alternaria_ was pathogenic on seedlings. The other organisms showed an effect on the seedlings, but because of the contamination of the controls, we have not yet been able to draw conclusions about these organisms.

TABLE 49. PATHOGENICITY TEST SUMMARY

Test Organism	# Plates (10 seeds per plate)	Mean % Germination	Mean % Seeds Diseased	Mean % Seedlings Diseased	Mean % Diseased Seedlings with Test Organism
Control	12	95.8	0.8	31.7	NA
Mucor	6	80.0	3.3	25.0	93.3
Curvularia	6	88.3	1.7	26.7	55.8
Aureobasidium	6	83.3	3.3	38.3	53.3
Alternaria	6	91.7	8.3	45.0*	49.6
Ulocladium	6	85.0	6.7	33.3	92.2
Penicillium	6	60.0	5.0	21.7	93.8
Fusarium _roseum_	5	82.0	0	32.0	74.7

Field Study, 1975-1976.

The field study of 1976-1976 involved 4 vegetation plots located across the air pollution gradient, CAO, BF, HB, and HV. Seeds were planted in 0.4 meter square areas (mini-plots) with 49 seeds per square in these plots. The mini-plots were either open or screened, and some were litter covered while others were bare mineral soil. The basic design is given on page 188 of the 1975-1976 EPA Progress Report.

Results--

Predation by birds and small mammals was extremely heavy on seeds in unscreened miniplots. Only about 3% of the seeds on unscreened plots without litter survived to germination, and only 1% of the seeds survived to germinate on the unscreened plots with litter. It appears that animals were primarily the cause of the mortality in the plots without litter, while in the plots with litter a combination of animal predation and seed pathogens depressed survival even further. There was no significant difference among the four vegetation plots because of high variability among the individual mini-plots. Results for the screened mini-plots are given in Table 50 and 51. Germination as checked in May 1976 averaged about 62% of the seeds in the screened plots without litter had survived to germinate, while only about 20% of the seeds in the screened, plots with litter had survived (Table 50). Two-way analysis of variance among the 4 vegetation plots and between litter and no litter showed the differences to be non-significant among the vegetation plots but the differences were highly significant (.001 level) between litter and no-litter plots. It is believed that seed pathogens found mostly in the litter were primarily responsible for this difference in germination rate.

In July of 1976 the numbers of living seedlings remaining alive had been greatly reduced from the number germinated. Table 51 gives the means per mini-plot of surviving seedlings in July. Compared to the number germinated, about 16% had survived in the no-litter mini-plots while 5% had survived in the litter mini-plots. Seedling damping-off pathogens were believed responsible for part of the mortality, especially in the late spring, but by mid-summer drought was the major factor. The driest plot, HV, had no surviving seedlings by July in the no-litter mini-plots, and only 1 in the litter mini-plots. The damping-off fungi appeared to have a greater effect on the seedlings in the litter mini-plots. An analysis of variance showed the difference between litter and no-litter to be highly significant (.001 level) while the differences among vegetation plots was marginally significant (.10 level). The vegetation plot differences were due primarily to the high mortality at HV because of drought. No smog effects were apparent; if smog effects were present, they were obscured by the rainfall differences between plots and the small sample size.

The results of this study pointed to the need of an expanded study with higher sample numbers and the addition of a control variable for soil moisture content.

TABLE 50. 1975-1976 SBNF SEEDLING ESTABLISHMENT FIELD STUDY, GERMINATED SEEDS, MEANS PER SCREENED MINI-PLOT IN MAY, 1976. FORTY-NINE SEEDS WERE PLANTED IN EACH MINI-PLOT.

Vegetation Plot	CAO	BF	HB	HV	Mean of Plots
No Litter	30.0	34.0	32.0	26.0	30.0
Litter	13.0	12.0	7.1	6.4	9.7

TABLE 51. 1975-1976 SBNF SEEDLING ESTABLISHMENT FIELD STUDY, SURVIVING SEEDLINGS, MEANS PER SCREENED MINI-PLOT AS OF JULY, 1976. FORTY-NINE SEEDS WERE PLANTED.

Vegetation Plot	CAO	BF	HB	HV	Mean of Plots
No Litter	5.9	8.1	5.6	0	4.9
Litter	0.1	1.3	0.3	0.1	0.4

Field Studies, 1976-1977.

The seedling establishment field studies of 1976-1977 consisted of one primary study (Seedling Air Pollution Study - SAPS) and two supplementary studies (Supplementary Seedling-Animal Study -SAAS, and Supplementary Litter-Seedling Study - SLSS).

The objective of the SAPS study was to determine air pollution and moisture effects on the survival of young seedlings in the San Bernardino mountains. The first supplementary study (SSAS) was designed to determine relative rates of seed predaton by small mammals vs. birds on the forest floor. The second study (SLSS) was designed to test the potential for seed survival and germination in different types of litter under natural conditions.

Primary design (SAPS)--

Healthy Jeffrey pine seeds were planted on four vegetation plots, two (BF and CAO) with relatively high air pollution and two (HV and HB) with low air pollution. Each vegetation plot was subsampled with four subplots, and each subplot had 16 mini-plots consisting of screened 15 x 15 inch frames planted with 49 seeds per frame. Twelve of the 16 mini-plots had the litter layer completely removed prior to planting, while 4 were placed on undisturbed, natural pine litter. One of the 4 subplots on each vegetation plot was chosen as a "water" subplot. These subplots were periodically (once a month or as necessary) watered with an amount of water necessary to simulate a heavy rainfall month. This amount was defined as the mean rainfall for each specific month over the past 25 years at Big Bear Lake Fire Station, plus one standard deviation. On each field trip to the study plots (done every 3 to 4 weeks during the spring, summer, and fall of 1977) soil samples were taken from 4 mini-plots (two with litter and two without) on each water subplot, and 2 mini-plots (one litter and one no-litter) for each of the other subplots. Moisture content of the soil from these samples was determined in the lab. On each field trip data was taken on surviving seedlings and dead seedlings, and all dead seedlings were removed. Possible mortality causes and plot disturbances were noted. Seedling data was not taken on those mini-plots used for soil sampling.

At the end of the field season, analyses will be made on seedling mortality by plot, considering the variables of soil moisture and rainfall, for each 3 to 4 week period. Rainfall and oxidant exposure data from other projects will also be used to try to relate periods of greatest mortality with corresponding environmental conditions.

Supplementary design (SSAS)--

Four subplots were chosen on pine litter covered areas of CAO, and 6 mini-plots (15 x 15 inches) were planted with 49 sound Jeffrey pine seeds each in the fall of 1977. On each subplot, three of the mini-plots had the litter layer completely removed, while on the other three the litter was undisturbed. On each litter type, one plot was completely screened to exclude all vertebrates, one was closed except for a narrow gap at ground level, which would allow small mammals to enter, and one plot was completely open.

The following table is a summary of the percent of seeds that survived to germinate:

	No Litter	Litter
Completely screened	20.9%	3.6%
Screened top, open base	0.5%	0.5%
Open top	1.5%	0%

The seeds used in this test showed an 85% germination rate under sterile lab conditions. The results indicate that in the case of the completely protected mini-plots, 65% of the additional mortality was due to pathogens and/or arthropods. In the case of the protected litter mini-plots, an additional 16% mortality occurred. The results from the open base mini-plots and open top mini-plots indicate nearly complete mortality (the total number of seeds surviving to germination on these mini-plots was only 5 of 784, or 0.6%). Since the open base mini-plots had about the same survival as the open top mini-plots, it can be concluded that small mammals were probably most important in seed predation. Broken seed coats and scat (mouse droppings) were observed around most of these mini-plots.

Supplementary design (SLSS)--

On one vegetation plot (CAO), seven different major types of litter cover were selected:

1. Jeffrey light litter (with PP and Oak)
2. Jeffrey heavy litter (with PP and Oak)
3. Oak litter (with PP and JPO
4. Mixed Jeffrey - Ponderosa - Oak litter
5. White Fir (with JP, PP and Oak)
6. Bare ground with some JP, PP needles
7. Bare ground with some grass

Two areas were found for each of the above litter types. On each areas, 6 mini-plots, (.4 x .4 m) were established at random and marked by stakes at two corners. On each of three of the mini-plots 49 seeds were placed, while the other three received 16 seeds each. Litter depth and % cover were recorded for each mini-plot.

The seeds were planted on November 3, 1976. All the plots were rechecked on April 20, 1977. This check showed no visible seedlings on any of the mini-plots. Further checks will be made in the fall of 1977 to see if any seedlings have become established.

Miscellaneous field activities--

During the fall of 1976 cones were collected from several healthy Jeffrey pines in the SBNF. No cone trees with significant smog damaged were found at this time. Seeds from the healthy tree cones were used in the studies described above.

Cones were again collected in August, 1977. This time both smog damaged and healthy trees were located (both Jeffrey and Ponderosa pines). The cones for each tree were measured, and the numbers of cones and yield of seeds were recorded for each tree. Tests of the cone data, seeds, and seedlings grown from them in the greenhouse will be made to determine if there is a relationship between cone, seed, and seedling quality land the degree of smog damage of the parent tree.

A pilot study was made in the fall of 1976 to determine if seed drop under natural conditions could be determined on the vegetation plots. Very few cone bearing trees were found on any of the plots. A few trees were found on CP, and a 30 x 30 meter subplot was established under these trees. Fifteen seed traps were placed randomly in this subplot, but no pine seeds were recovered. It is believed that seed drop was too small to be detected by the density of traps used.

CONE AND SEED PRODUCTION FOR DOMINANT CONIFER TREE REPRODUCTION

Introduction

The two primary objectives of this study are:

1) To test the hypothesis that cone crop abundance and frequency in ponderosa and Jeffrey pines are affected by ozone injury; and

2) To describe the probability that a tree with specified characteristics will produce a cone crop in a given year.

The rational for the cone study and the study design, methods, and tree characteristics used to classify the trees have been previously reported (Luck, 1977).

Recent Research Progress

Status in acquiring plot data other than the cone counts is presented in Table 52. A total of 9 pots have been completed, the data punched on IMB cards and the values on those cards verified against the original data.

These data sets have been forwarded to the data management group for entrance into the data bank. The other ten plots are in various stages of completion.

The annual cone crop data, 1973-1976, obtained by visually counting cones within the tree crowns, have been punched on IBM cards, verified and forwarded to the data management group for entry into the data management system. These counts have been reported by Luck (1977). The 1977 cone crop is currently being counted. Ground counts have been made of the whole cones, and of those eaten by squirrels during the 1976 cone crop. Insect damaged cones and cones which aborted before maturing were placed in rearing containers. Cones from the 1975 crop that were placed in rearing are being processed. The insect species assciated with a particular type of damage is being identified so that damaged cones can be identified in the future, even though the insects causing; the damage are absent. Curation of insects reared from damaged cones obtained from the 1974 and 1975 cone crops has been partially completed. We are waiting for the return of some specimens sent to several specialists for identification.

As an example of the way in which the data is being analyzed, Figures 29, 30, 31 and 32 present annual cone crop data (combined visual counts for the 1974-76 cone crops) for ponderosa and/or Jeffrey pine trees on three

TABLE 52. STATUS IN ACQUIRING PLOT DATA ON THE 19 STUDY PLOTS LOCATED IN THE SAN BERNARDINO MOUNTAINS OF SOUTHERN CALIFORNIA.

	Data Type					
Plot ID	Tree age	Crown height	Tree height	Keen class	Crown class	Data verified and entered into data management system
UCC	X	X	X	X	X	X
HB	0	X	X	0	X	
COO	X	X	X	X	X	X
SF	X	X	X	X	X	X
CP	--	X	X	0	--	
DW	X	X	X	X	X	X
SV.I	X	X	X	X	X	X
TUN2	X	X	X	X	X	X
GVC	X	X	X	X	X	X
BP	X	X	X	X	X	X
NEGV	X	X	X	X	X	X
HV	X	X	X	0	X	
DL	X	X	X	0	0	
CAO	X	X	X	0	X	
CA	X	X	X	--	X	
BF	0	0	0	0	—	
SC	0	0	0	0	0	
SCR	X	0	X	0	0	
BL	--	0	0	0	X	

Key: X = complete
-- = partially done
0 = not started

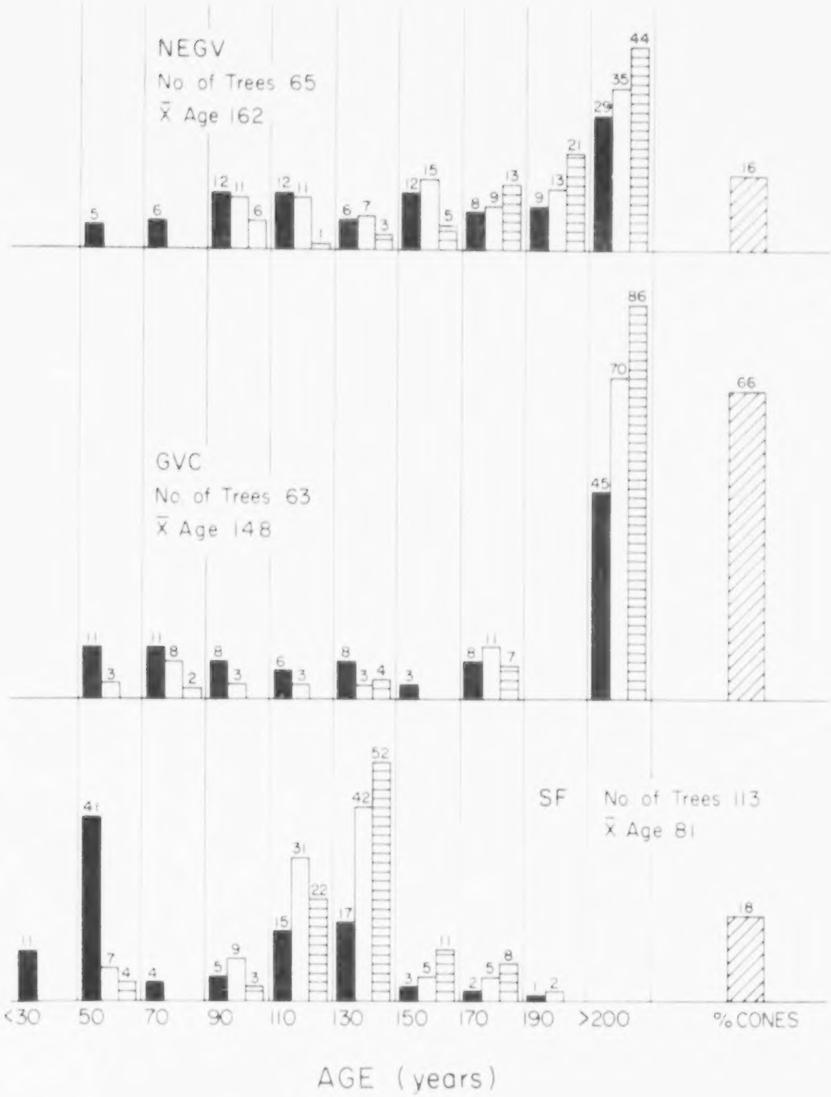


Figure 29. Age class distribution of ponderosa and/or Jeffrey pine trees on three plots. Solid bars = % of trees in each age class; Open bars = % of cone bearing trees in each age class; Horizontal hashed bars = % cones produced per age class; Diagonally hashed bars = % of the combined three plot cone production.

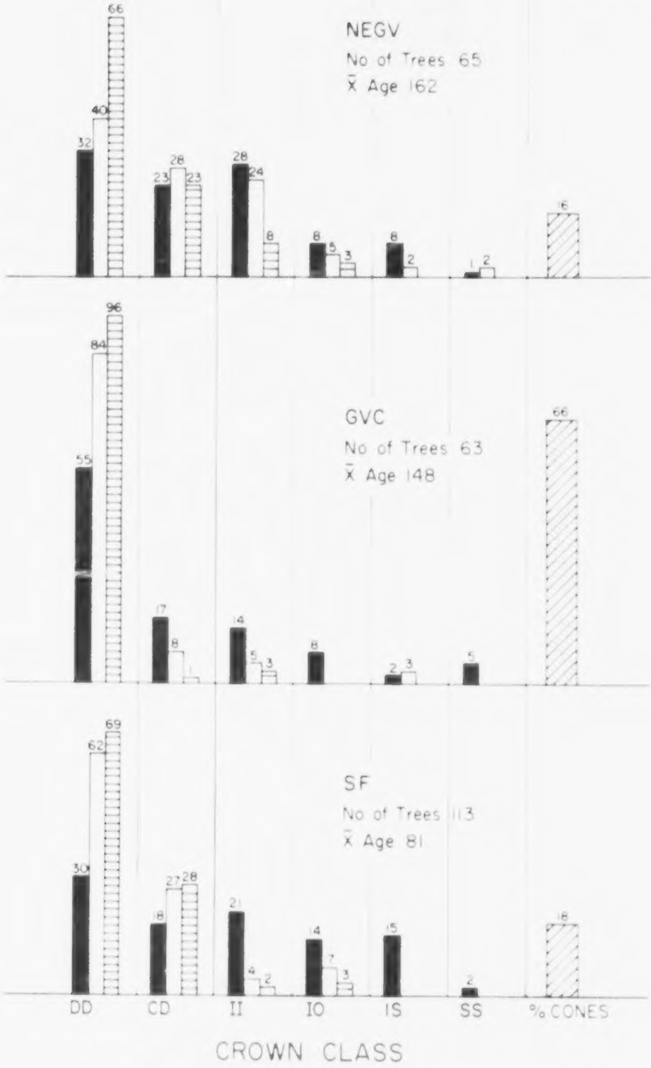


Figure 30. Crown class distribution of ponderosa and/or Jeffrey pine trees on three plots. Solid bars = % of trees in the six specified crown classes; Open bars = % of trees bearing cones in a crown class; Horizontally hashed bars = % of cones with respect to crown class of cone bearing trees; Diagonally hashed bars = % of the combined three plot cone production. DD-Dominant; CD-Co-dominant; II-Intermediate; IO-Intermediate open; IS-Intermediate suppressed; and SS-suppressed.

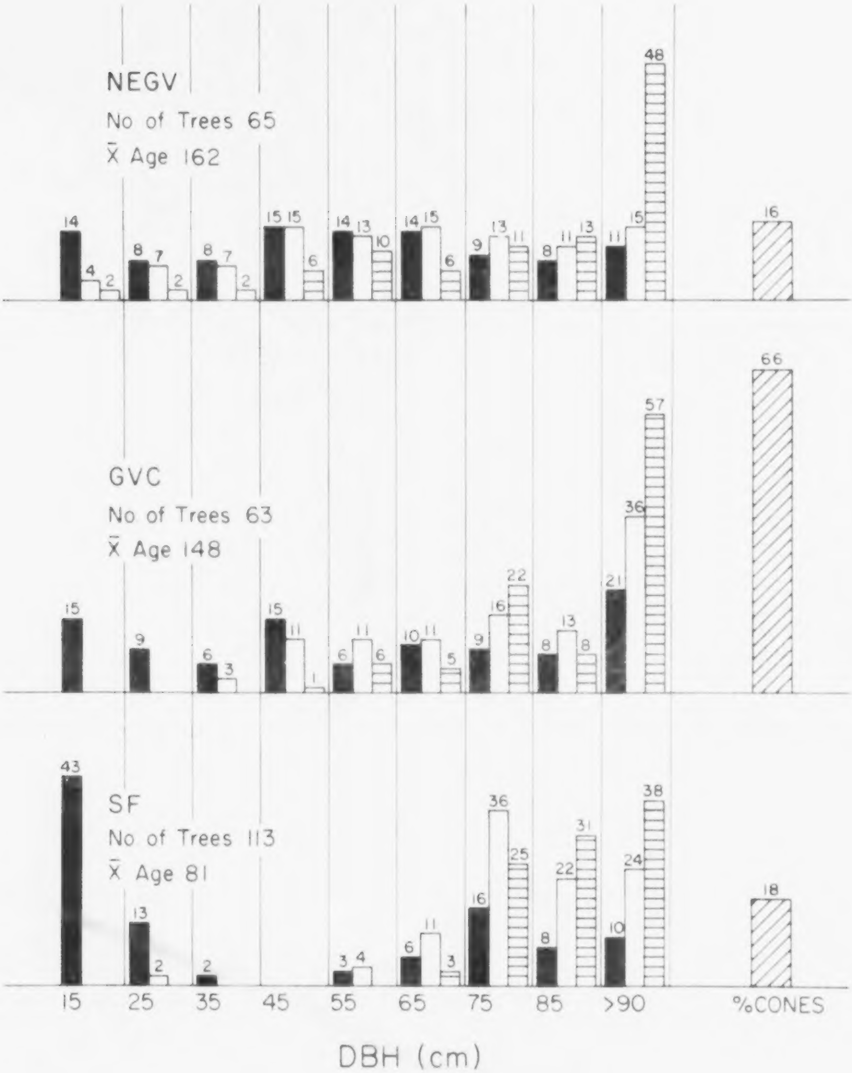


Figure 31. Diameter class distribution of ponderosa and/or Jeffrey pine on three plots. Solid bars = % of trees in specified diameter classes; Open bars = % of trees in a diameter class that produced cones; Horizontal hashed bars = % of cones with respect to diameter of cone bearing trees; Diagonally hashed bars = % of the combined three plot cone production.

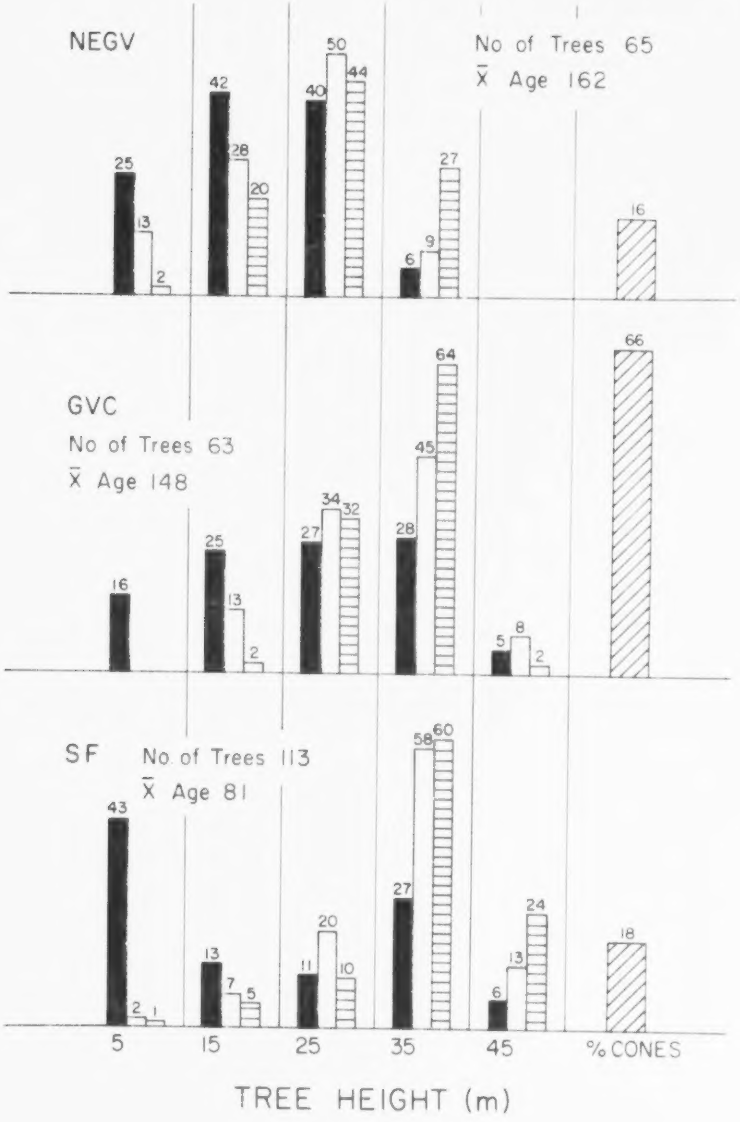


Figure 32. Height class distribution of ponderosa and/or Jeffrey pine on three plots. Solid bars = % of trees in the five height classes; Open bars = % of trees in each height class that produced cones; Horizontally hashed bars = % of cones produced with respect to height of cone bearing trees; Diagonally hashed bars = % of the combined three plot cone production.

plots, Northeast Green Valley (NEGV), Green Valley Creek (GVC) and Sky Forest (SF). The trees from these plots are classified into groups based on 20 year age intervals (Fig. 29), crown classes (Fig. 30) (see Luck, 1977, for a description of the crown classes), 10 cm intervals in diameter (at breast height) (Fig. 31), and 10 m intervals in tree height (Fig. 32).

The first point to note is that NEGV and GVC have older trees present on the plots (Fig. 29). Trees 200 years or older are absent from SF. The lack of older trees on SF is due to the logging history on that plot. The 200+ year class of trees, however, produces more than its share of cones. For example, trees in the 200* year class at NEGV represent 35 per cent of the trees bearing cones and bear 44 per cent of the cone crop (total number of cones) while they make up only 29 per cent of the stand. This pattern is even more pronounced at GVC. Trees in the 200* year class represent 45 per cent of the stand but account for 70 per cent of the trees producing cones and bear 85 per cent of the cone crop. The older trees, age classes 130, 150, 170, show the same trend at SF. Clearly the older trees are the greatest source of cones and, thus, of seed as well.

Crown class is perhaps the most important tree characteristic linked to cone production (Fig. 30). Clearly, dominant trees are the greatest source of seeds because they contribute more than their share of cones and seeds based on their representation in the stand.

The larger diameter (Fig. 31) and taller trees (Fig. 32) are also disproportionate contributors to the seed crop. However, both these variables are correlated with tree age and crown class (dominant trees are usually the taller and larger diameter ones); hence, these variables may explain little or no variation in crown crop abundance when they are corrected for covariance with other variables.

Ozone damage classes were not represented by a sufficient number of trees on these plots to permit assessment of the effect of this variable on cone production. It should be used to reclassify; tree only within a crown class or age class. For example, given that a tree belongs to the dominant crown class, how does ozone damage effect the cone crop produced by that class? Thus, before the effects of ozone damage can be assessed, the pattern of cone produciton as influenced by a number of other variables, such as age and crown class, needs to be determined first. Furthermore, since cone crops vary substantially in abundance, a number of years of data are essential before the pattern of cone production can be revealed.

LITTER PRODUCTION SUBSYSTEM

Introduction

Oxidant air pollution stimulated development of the abscission zone and thus induced heavy defoliation, especially on yellow pines. The rate of needle fall in the early stages of impact increased markedly and later decreased to zero as the tree was increasingly defoliated and finally killed. The question here is how does the change in rate of needle and branch mortality and the consequent change in addition of needle and branch litter affect the nature and amount of organic litter covering the soil? Further, are there consequent effects upon: the soil moisture and temperature; seed germination; seedling survival; and the forest floor as a habitat for micro- and macroorganisms? Since defoliation also results from other plant damage (pathogens and insect attack) there is also a question as to the effect of air pollutants in relation to other causes of defoliation.

As foliage of the canopy is damaged and the density is altered, it is postulated that both chemical composition and amount of crown drip falling on the soil during periods of precipitation will be altered. Here the question is, do changes in crown drip and throughfall precipitation affect the soil and the forest floor; and if so, are there consequent effects?

Research Objectives

The objectives of this project relative to oxidant injury gradient were as follows:

1. Continue and expand the measurement of litter production from individual trees on all major plots.

2. Continue to measure nutrient content of needle fall and accumulate litter under individual trees variously affected by oxidant air pollutants.

3. Verify with expanded data the effect of oxidant pollutants on needle size in the litter.

4. Measure accumulated litter under all trees for which data were being collected.

Materials and Methods

Measurement of litter production--

Litter was collected as it fell on 46 cm square screens under 50 yellow pines (*P. ponderosa*, *P. Jeffrey*) on 16 plots. Collections from the screens were made in the late spring and late fall in both 1975 and 1976, expanding the number over that of 1974 which was 39 trees. Two to four screens were used under each tree depending upon crown size. The litter was oven-dried, separated into needles and other material (twigs, etc.) and weighed. A large number of intact needle-fascicles were separated, counted and weighed to obtain the mass per fascicle as a measure of needle size. The total needle component of the litter was analysed for (N, P, K, Ca and Mg).

Needles were digested by the Johnson and Ulrich (1959) procedure in preparation for nutrient analyses. Nitrogen was measured by a modified Kjeldahl method from Black (1965) and phosphorous was determined by a colorimetric method of Richards in a book edited by Jackson (1960). Atomic absorption was used to measure the concentration of cations.

Results and Discussion

Pine Litter Production--

Litter collected under pine trees during 1975 (47 trees) and 1976 (41 trees) on 18 major vegetation plots was analysed for total litter deposit, total needle component and size of needle fascicles (mass per fascicle) in relation to oxidant injury rating. Needles were also analysed for content of N, P, K, Ca and Mg.

Amount of litter--Dry weight of needles collected during late autumn of 1975 and 1976 as related to oxidant injury score is shown in Figure 33. The increase in needle fall from relatively healthy trees (score >31) of 87.5 gm/m^2 to 256.5 gm/m^2 from severely affected trees (score 8 to 15) was statistically significant (P=.01) as is the decline to 125.7 gm/m^2 from severely affected trees (score 8 to 15) is statistically significant (p = .01) as is the decline to 125.7 gm/m^2 from very severely affected trees (score 0 to 7). The total amount of litter of all kinds collected on the screens followed almost exactly the same pattern, with litter other than needles (twigs, branches, etc.) contributing about 33 percent of the total.

An important impact of oxidant air pollutant was to increase the litter fall during the period of tree injury from the onset of clearly discernable injury (score 30) until the tree died. If the duration of this period is assumed to be 8 years, then the litter fall would be almost exactly double that expected from unaffected pine trees. After the first year following death of the tree, needle fall is very small, but a vast increase in dead branches (woody litter) may be added. The net result is predictable, namely that the amount of undecomposed litter on the forest floor is increased and thus the fire hazard increased during the injury period and for a number of years following the death of the pine trees.

In addition to the fire hazard created by increase litter fall, the extra thickness of fresh loose litter created on the forest floor can be expected to have a marked detrimental influence on seed germination and seedling survival during and following the period of oxidant injury and tree

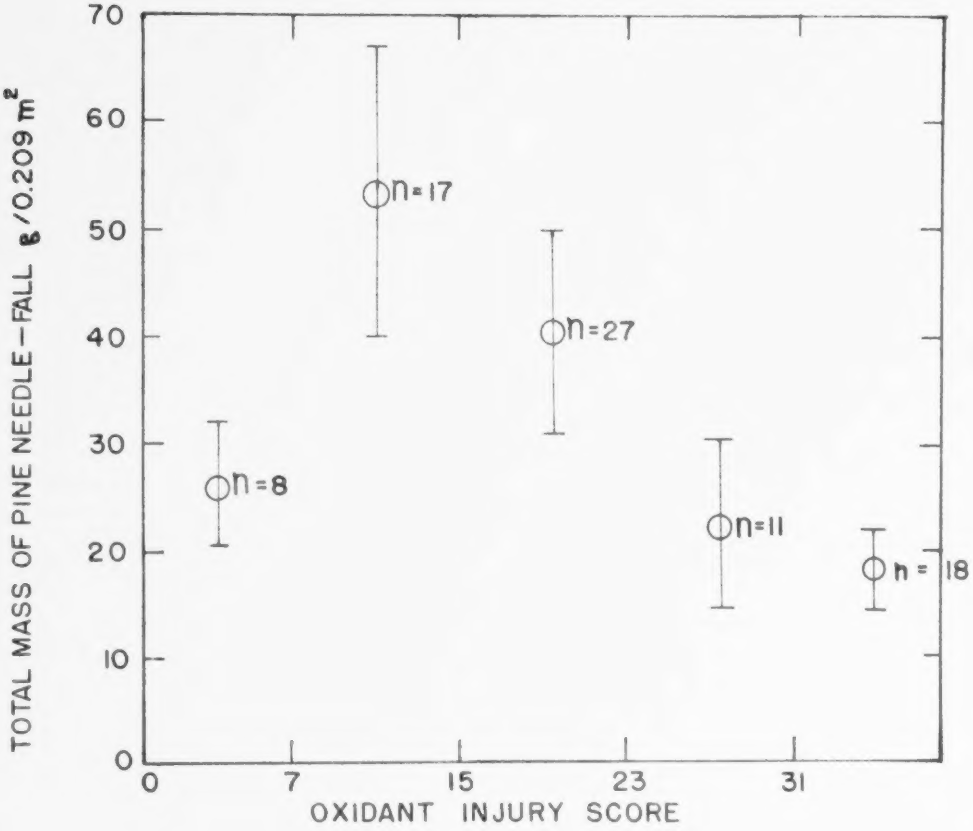


Figure 33. Total pine needle litter collected related to oxidant injury score 1975 and 1976.

mortality: this aspect of litter fall is being investigated by others on the project.

Size of needles in the litter--The size of needles as measured in grams per fascicle (cluster of 3 needles) by counting and weighing a large number of inteact fascicles separated from the total litter collected by the screens was determined for each tree. The data showed clearly that as oxidant injury increased, size of the pine needles decreased. The relationship was almost identical for 1975 and 1976 (difference between the regression lines was not significant). Least squares linear regression for the combined years is $N_m = .01665 + .0073$ IR, where N_m is mass per fascicle in g/m^2, and IR is the oxidant impact rating scaled with increasing scores indicating decreasing injury. The correlation $r = .392$ is very highly significant ($P = .001$) although there is considerable scatter about the regression line (Fig. 34). Considering the usual variability in biological systems, it appears safe to conclude that the oxidant injury rating system does reflect the general health of the pine trees. Stratification of the data by grouping into either high and low rainfall plots or into ponderosa pine and Jeffrey pine does not give increasing reliability, although the correlation for the high rainfall plot was higher ($r = 0.536$) and the regression line somewhat steeper ($N_m = 0.145 + .00158$ IR). However, the difference from the general equation does not appear to be very significant.

Plant Nutrient Content of Needle Litter--

The content of nitrogen (N), potassium (K), phosphorous (P), calcium (Ca), and magnesium (Mg) in the needles collected on the screens in 1975 and 1976 were determined and the relationship with oxidant injury ratings and needle size was analysed by linear regression.

The content of N, P, and K in the needles which fell tended to increase with increasing oxidant injury and declining needle size. Ca, on the other hand, decreased and Mg appeared to be variable, but with no consistent trend. It appears that as needle mass decreased the carbohydrate content and N, P and K content per fascicle remained about constant so that the concentration increased, a simple dilution relationship. This can be seen from the ratios given in Table 53 where for a 49.5 percent increase in needle size in high rainfall plots, concentration of N decreased by 50 per cent. The relationship was not quite as exact for phosphorous (P), and was still less exact for potassium (K) especially in the high rainfall plots. The increase in Ca concentration with increasing needle size appeared to be explainable in that Ca is involved in carbohydrate in cell wall material so the larger needles take in more calcium as the cells enlarge. Relationships between N content, versus oxidant injury score are shown in Figures 35 and 36; for K content in Figures 37 and 38; for P in Figure 39 and 40; and for Ca in Figures 41 and 42.

Phosphorous in the Surface Soil--

A discussion of phosphorous in the surface soil is included here as it is postulated that plant nutrients in the surface soil may be affected by the nutrient content of the litter. The soluble soil phosphorous in the

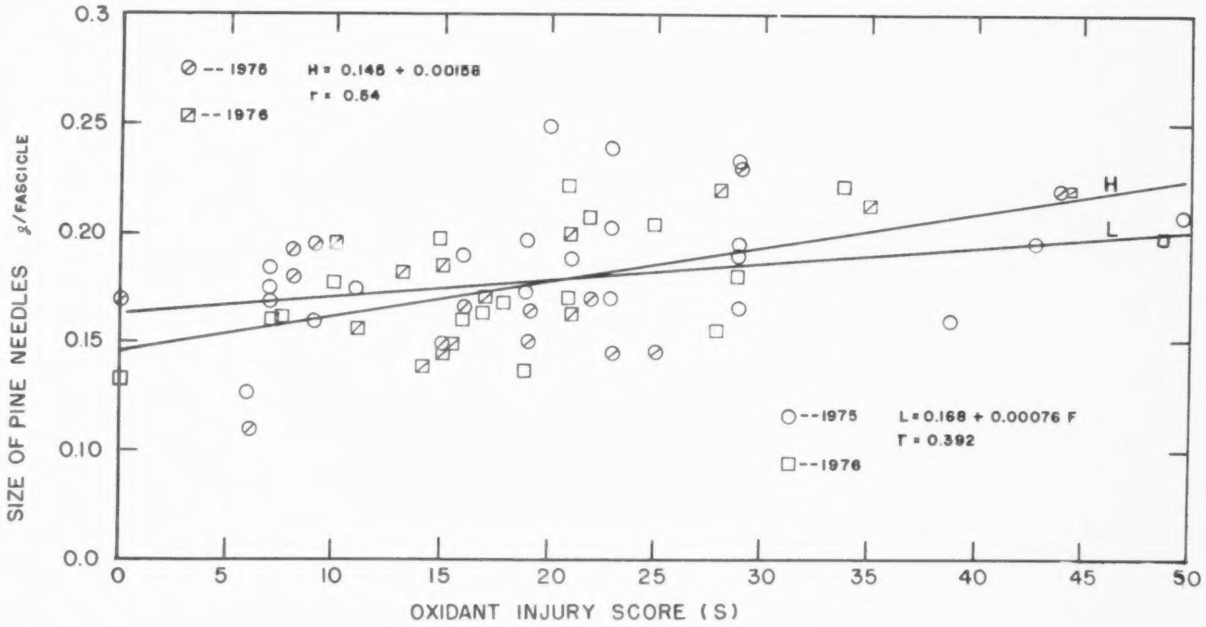


Figure 34. Size of pine needles in needle litter collected related to oxidant injury score.

TABLE 53. NEEDLE SIZE AND CONTENT ON N, P, K AND Ca IN NEEDLES COLLECTED ON SCREENS.

	High Rainfall Plots		Ratio Smaller/ Larger	Low Rainfall Plots		Ratio Smaller/ Larger
Oxidant Injury Score*	0	50		0	50	
Needle Size gm/fascicle*	0.124	0.25	0.495	0.168	0.20	0.84
Percent N in needles*	0.688	0.34	0.50	0.542	0.438	0.81
Percent K in needles*	0.48	0.11	0.23	0.36	0.23	0.64
Percent P in needles*	0.096	0.042	0.44	0.076	0.055	0.72
Percent Ca in needles*	0.294	0.453	0.65	0.243	0.582	0.42

*NOTE: 0 oxidant injury score is very severe injury and 50 is a health tree with no evident injury. The numbers in the body of the table are average values derived from regression analysis.

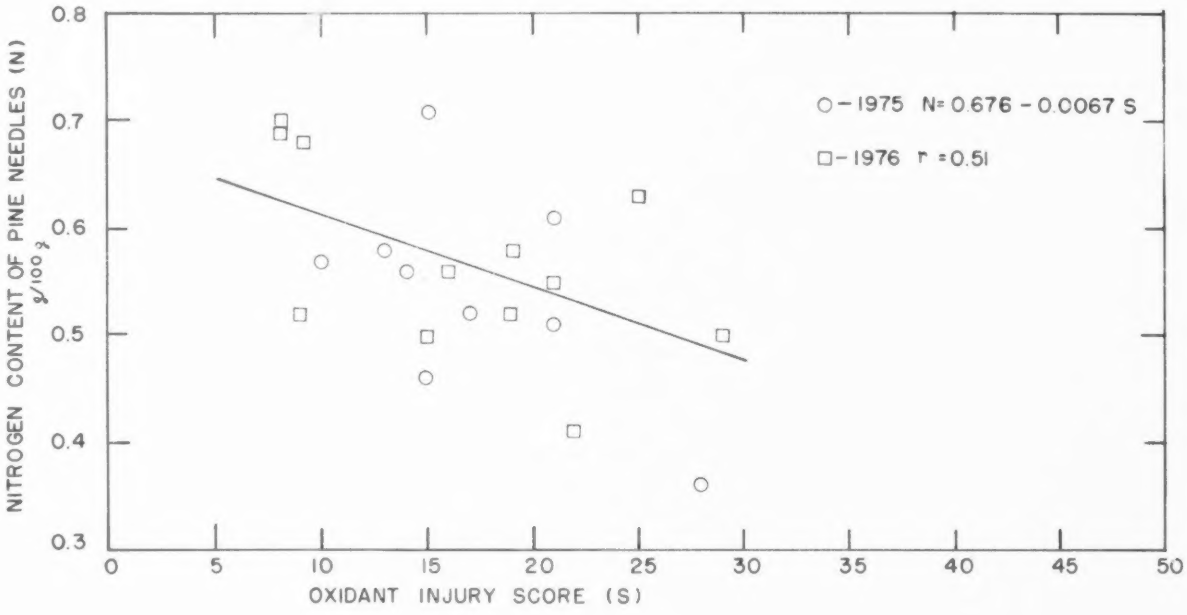


Figure 35. Nitrogen content of pine needle litter related to oxidant injury score--high rain fall plots.

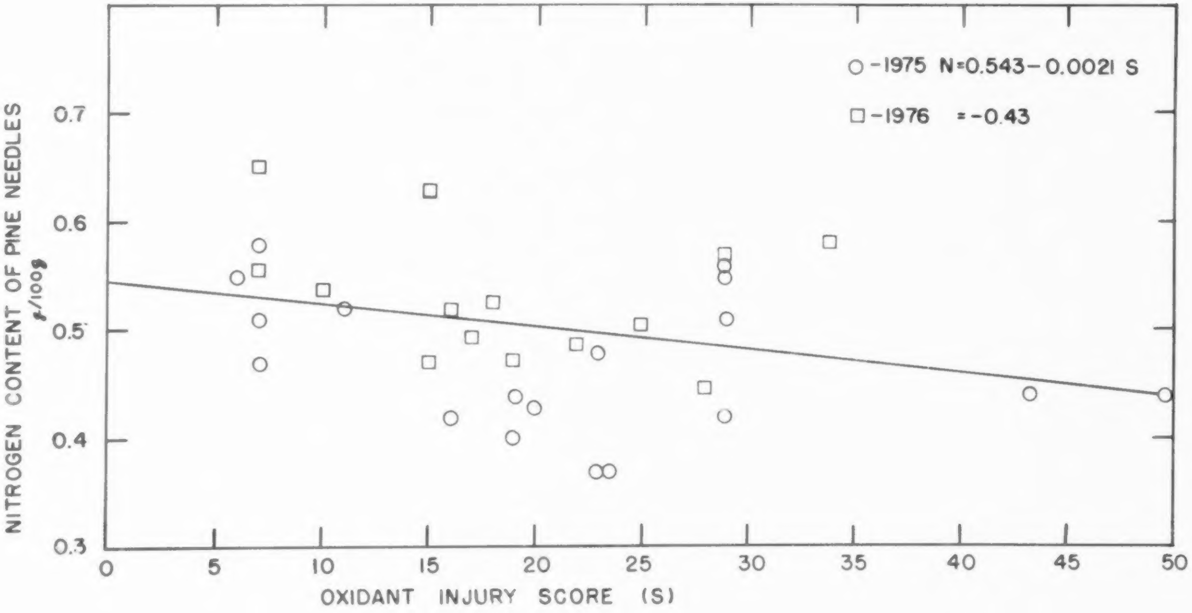


Figure 36. Nitrogen content of pine needle litter related to oxidant injury score--low rainfall plots.

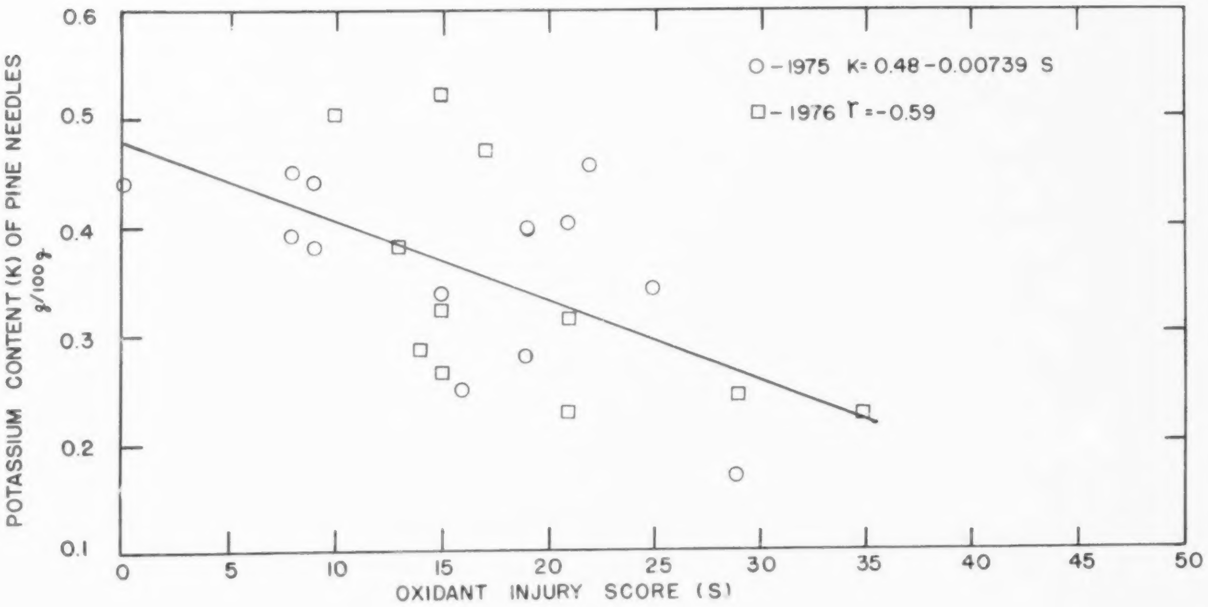


Figure 37. Potassium content of pine needle litter related to oxidant injury score--high rainfall plots.

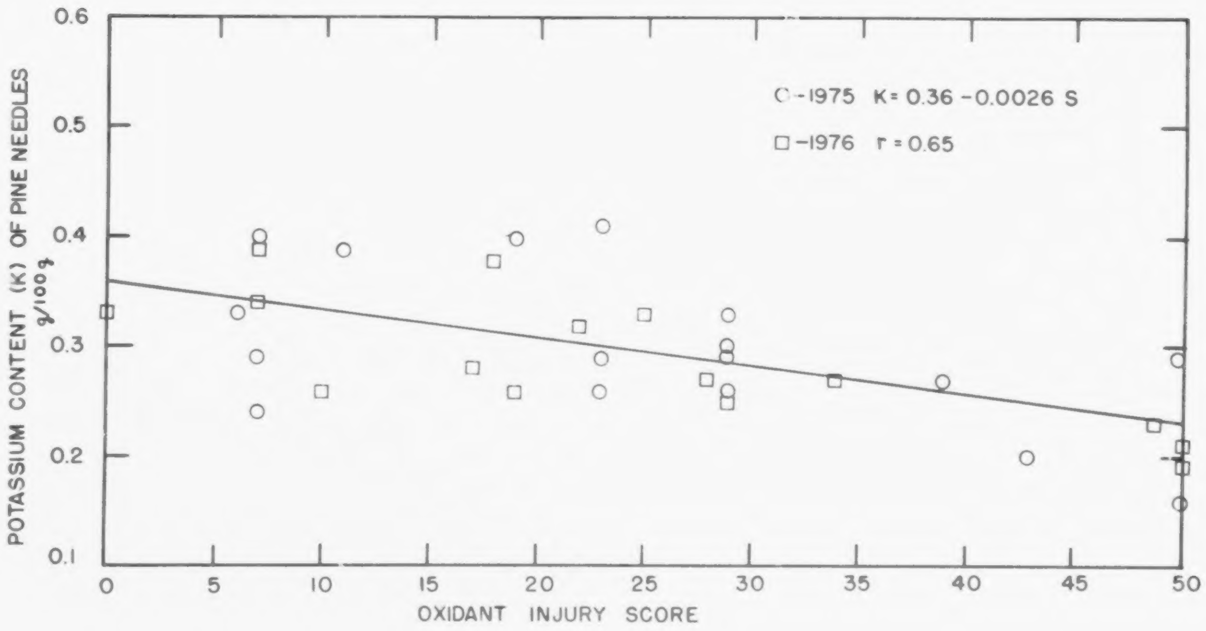


Figure 38. Potassium content of pine needle litter related to oxidant injury score--low rainfall plots.

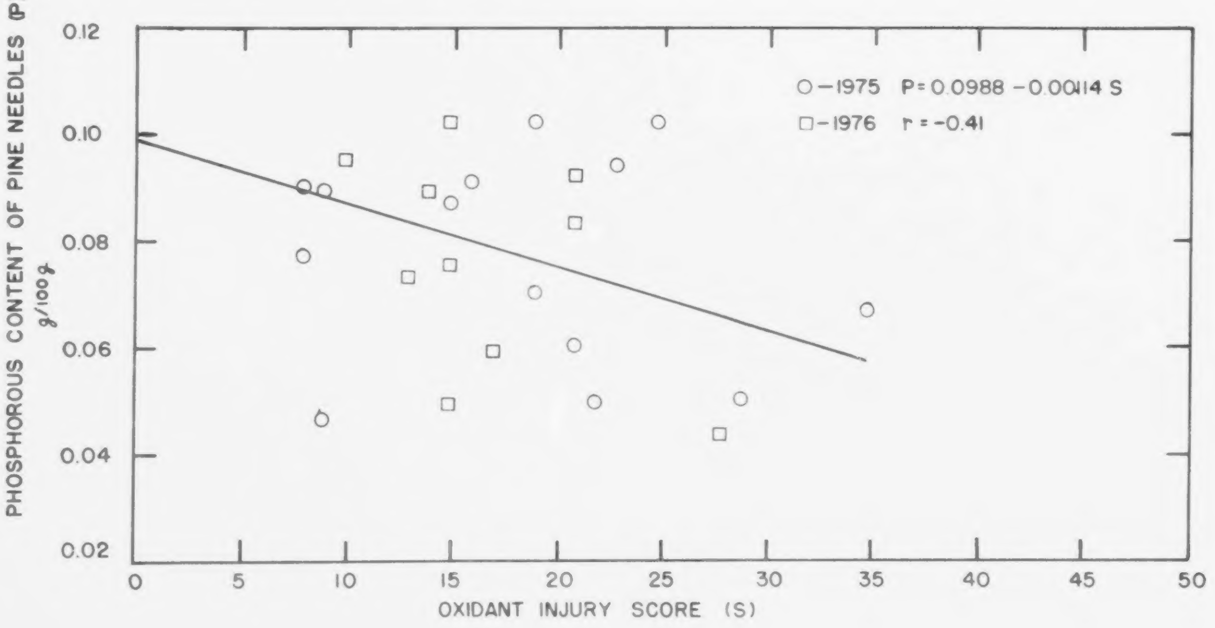


Figure 39. Phosphorous content of pine needle litter related to oxidant injury score--high rainfall plots.

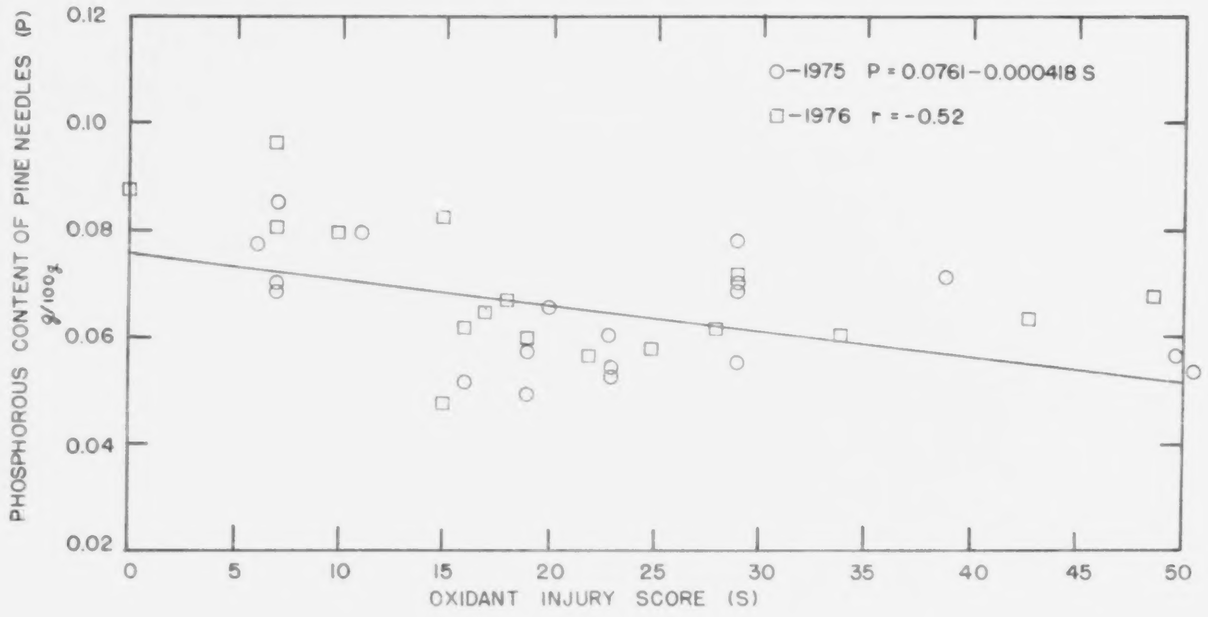


Figure 40. Phosphorous content of pine needle litter related to oxidant injury score--low rainfall plots.

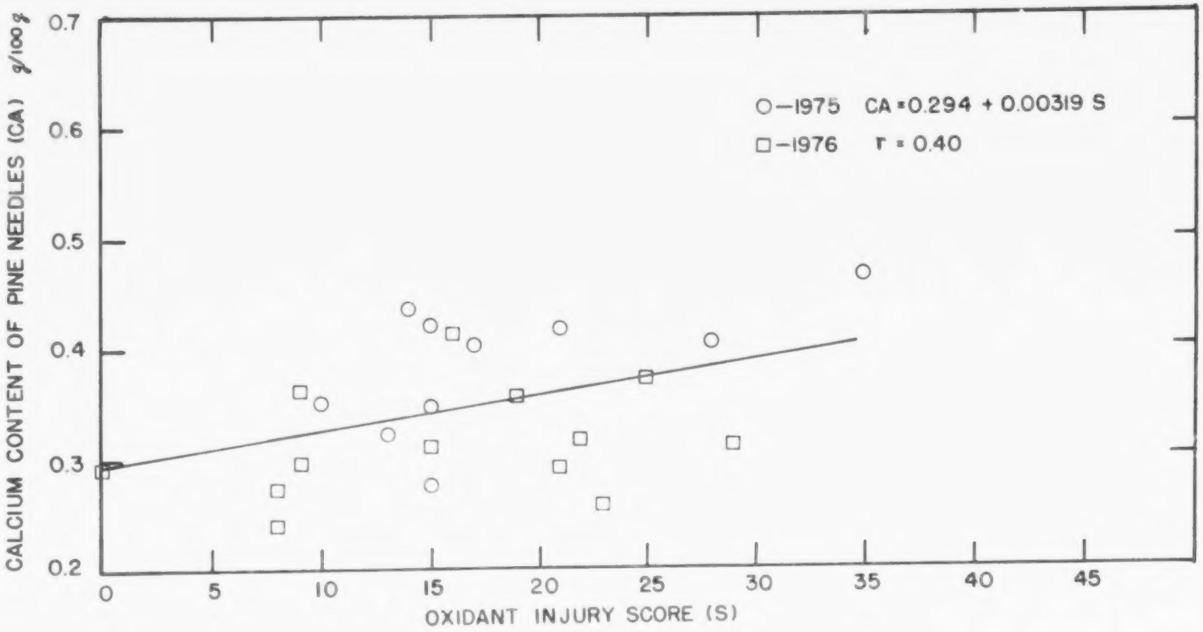


Figure 41. Calcium content of pine needle litter related to oxidant injury score--high rainfall plots.

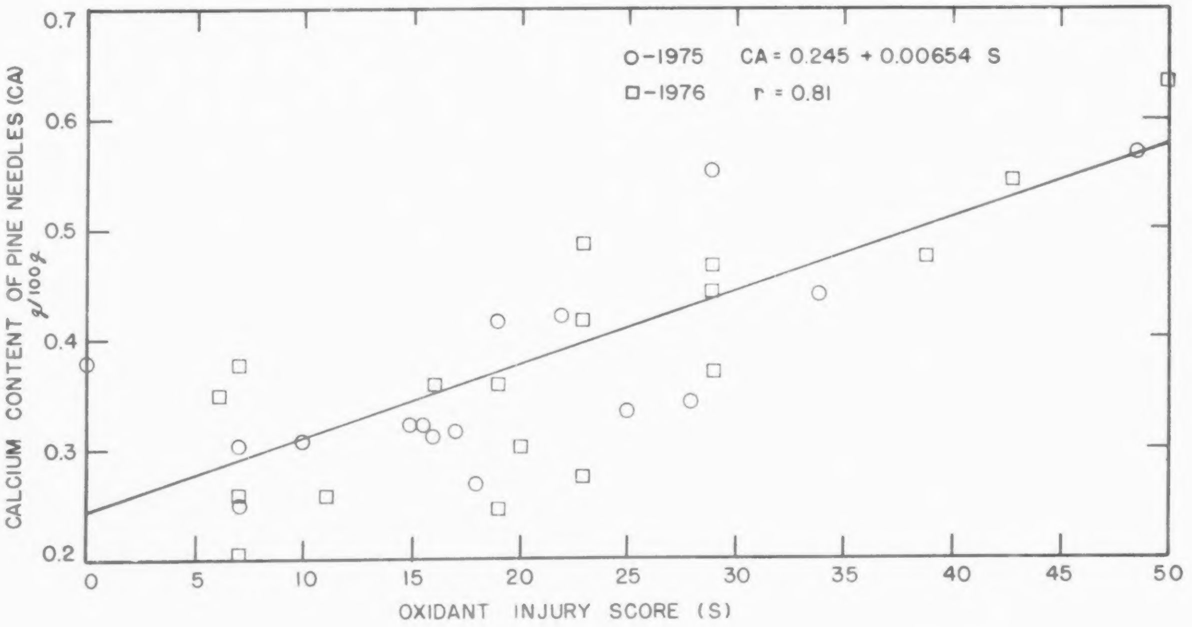


Figure 42. Calcium content of pine needle litter related to oxidant injury score--low rainfall plots.

upper 7.5 cm of soil sampled under pine trees of varying oxidant injury rating is shown in Figures 43 and 44. It can be seen that as the oxidant injury score approached zero (tree death) the soluble phosphorous in the soil increased. By comparing Figures 39 and 40 with Figures 43 and 44 it is evident that the slope of the regression lines for needle phosphorous content with oxidant injury score are similar to the regression lines for soluble phosphorous in soils with oxidant injury score. There is probably a causal relationship here, as postulated. Similar relationships were found for Ca, K and Mg however neither the Ca nor Mg content of needle litter increased with increasing injury by oxidant air pollutants.

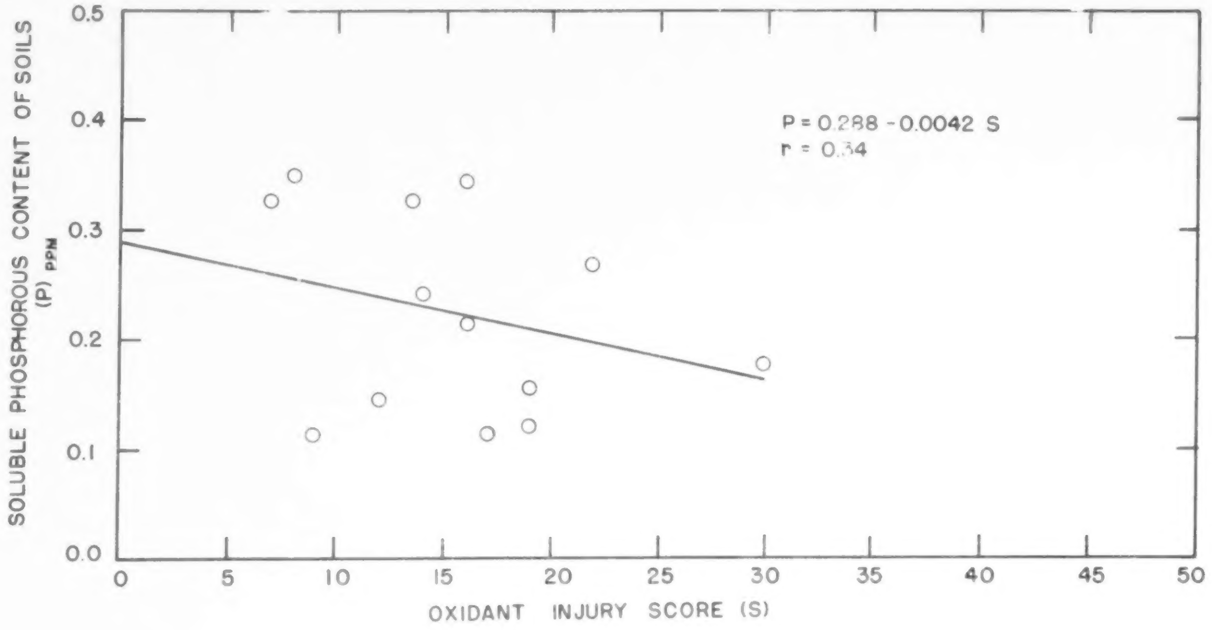


Figure 43. Soluble phosphorous content of surface soils related to oxidant injury score of pine trees--high rainfall plots.

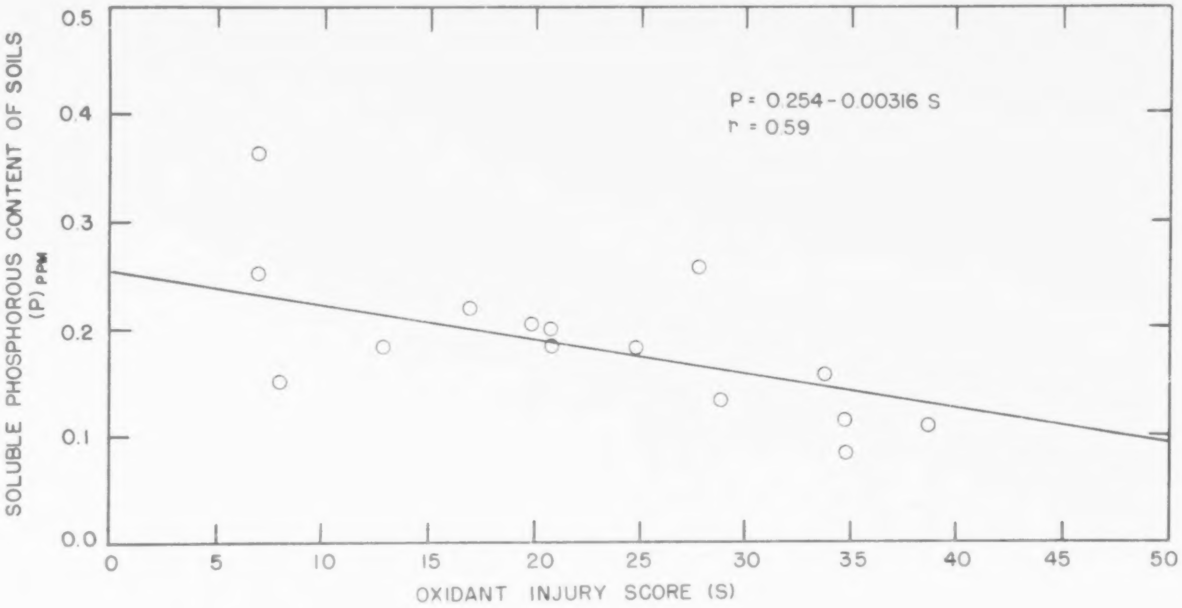


Figure 44. Soluble phosphorous content of surface soils related to oxidant injury score of pine trees--low rainfall plots.

FOLIAGE LITTER DECOMPOSITION SUBSYSTEM: MICROBIAL ACTIVITY AND NUTRIENT CYCLING

Introduction

There is a continual turnover of tree biomass in the forest as old foliage, branches, and trees die and fall and other grow to replace them. Litter decomposition and nutrient cycling are the means by which the living forest recovers much of the nutrition incorporated in this organic matter. Recovery of these vital nutrients is the function of the vast populations of litter and soil microflora and microfauna. This portion of the overall study is directed toward determining the influence of oxidant air pollution on microfloral populations and leaf litter decomposition (primarily of ponderosa and Jeffrey pines). Although previous work in this field is relatively sparse, reviews are available (Dickinson and Pugh, 1974).

Research Objectives

Three major research approaches are being implemented in this subsystem study. They include the following:

1) To quantify needle litter decomposition in the field. This will help determine the degree to which oxidant air pollution affects (a) the quality of needles as substrates for decomposers and as sources of nutrients for cycling, and (b) the capacity of naturally-occurring populations of litter micro-organisms to decompose pine needle litter.

2) To characterize and quantify microfloral inhabitant populations of pine needles from the period needle elongation through decomposition on the forest floor. This will suggest effects of oxidant air pollution on decomposer communities and provide a basis for laboratory studies of fumigation effects on decomposition.

3) To conduct laboratory fumigation experiments on both fungal growth and needle decomposition. These are expectd to clarify results obtained from field studies by eliminating such variables as moisture and temperature from consideration.

Materials and Methods

Needle Litter Decomposition in Natural Stands--

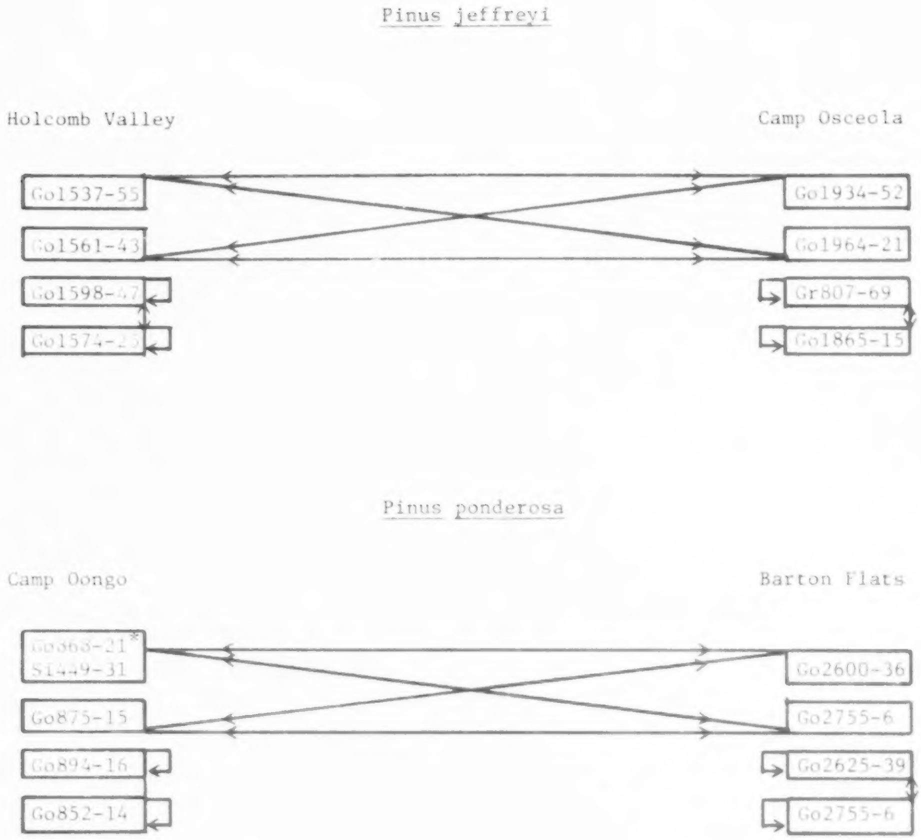
For this study, relatively isolated co-dominant and dominant trees were selected. Two each of the least and most oxidant-injured Jeffrey pine trees were selected on each of two sites. These sites were Holcomb Valley ("no" oxidant injury) and Camp Osceola ("moderate" oxidant injury). Similar selections of ponderosa pines were made at Barton Flats ("moderate" oxidant injury) and Camp Oongo ("moderate-heavy" oxidant injury). These sites represent the range of oxidant injury to each species on the study plos in the SBNF. During the autumns of 1974-1976, freshly fallen litter was sampled randomly beneath each selected tree and subsamples of approximately 15 gm were made at random. One random 20-gm subsample from each tree per year was analyzed by Drs. Gersper and Arkley for nutrient content. An additional random sample was dried to 30 C, allowing calculation of fresh/dry weight ratio for the entire sample. The remaining subsamples were placed in labeled nylon mesh (3 mm) envelopes (approximately 15 cm x 30 cm) and disbursed as related in Figure 45. Each arrow represents similar treatments consisting of 5, 10, and 30 envelopes left in the field for one winter, one year, and two years, respectively. The 1974 samples comprised the two-year experiment; the 1975 samples comprised the one-year and first one-winter experiment. The first one-winter experiment was repeated, and the second involved the exchange of ponderosa and Jeffrey pine litter between their respective sites (Fig. 46). The rationale for this is explained in the following discussion.

After each treatment was completed, envelopes were retrieved. The needles were: (1) brushed lightly to remove excessive inorganic and fungal materials; (2) dried to a constant weight at 30 C and (3) weighed.

A composite sample of the retrieved litter for each treatment in the two, one and first overwinter experiments was analyzed for percent content of N, P, K, Ca and Mg by Drs. Gersper and Arkley. Percent change in weight and nutrient content were then calculated.

Among the environmental variables which may influence litter decomposition are solar radiation, litter temperature, litter moisture and litter depth. Although litter moisture has not been measured, it is felt that careful interpretation of soil moisture depletion curves and precipitation, soil moisture and litter temperature data will permit the determination of the relative litter moisture relations between the four plots under consideration. Litter depth measurements have been taken for comparison between trees and plots. Solar radiation and litter temperature were measured once per hour, at four locations beneath each study tree from sunrise to sunset on a cloudless day in late August and early September. Solar radiation was measured with a Weather Measure Model R401 Mechanical Pyranograph. Temperature in the upper one cm of the organic horizon was measured with a calibrated mercury centigrade thermometer. Each measurement point corrsponded to the midpoint of one quarter of the arc along which decomposition envelopes were placed beneath each tree.

Envelopes of litter from the two and one year experiments were rated visually for activity in 14 categories of signs of decomposition. The total length of needles on each two and one year envelope was estimated by (1) counting the number of fascicles in each envelope, (2) determining the mean length per fascicle for one envelope per treatment and (3) multiplying this mean value by the number of fascicles in each


Pinus jeffreyi
Holcomb Valley
Camp Osceola
Go1537-55
Go1561-43
Go1598-47
Go1574-25
Go1934-52
Go1964-21
Gr807-69
Go1865-15
Pinus ponderosa
Camp Oongo
Barton Flats
Go868-21*
Si449-31
Go875-15
Go894-16
Go852-14
Go2600-36
Go2755-6
Go2625-39
Go2755-6

*1974 oxidant score (Go868 was killed by bark beetles and replaced in this study by Si449.)

Figure 45. Source and destination (tree tag-1976 oxidant score) of 960 decomposition study envelopes. Each arrow represents 30 envelopes and points from their source to their destination.

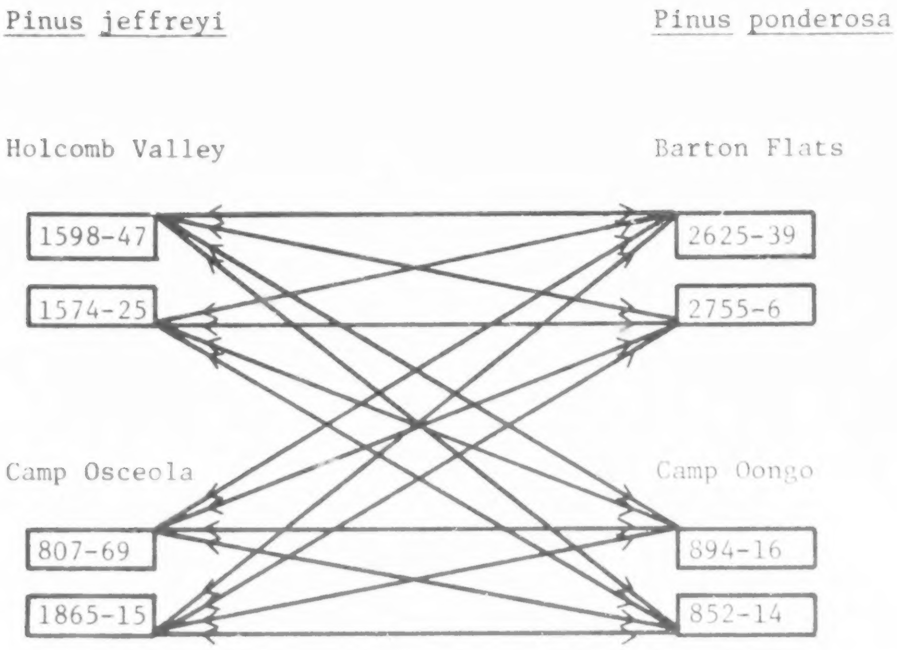

Pinus jeffreyi
Pinus ponderosa
Holcomb Valley
Barton Flats
1598-47
2625-39
1574-25
2755-6
Camp Osceola
Camp Oongo
807-69
894-16
1865-15
852-14

Figure 46. Source and destination (tree tag-1976 oxidant score) of 160 decomposition study envelopes. Each arrow represents 5 envelopes and points from their source to their destination.

envelope per treatment. Because each envelope per treatment constituted a random subsample from the same source, and each envelope contained approximately the same initial weight of needles (15 g), it was felt that the estimated total length of needles per envelope reflected their relative surface area.

All of the above data types will be examined for meaningful relationships to decomposition.

Decomposer microorganisms populations on pine needles in natural stands experiencing different oxidant doses--Oxidant air pollution may alter the rate of pine needle decomposition by affecting the composition of microbial populations on senescing and fallen needles. To study the succession of pine needle microorganisms, two lines of investigation were followed in the field. Microbial succession in living needles was determined by isolation of fungi from surface-sterilized needles of various ages, while succession in litter was determined by isolating fungi from surface-sterilized needles that were on the forest floor for varying periods of time.

Before litter fall in 1974-1976, one square meter of nylon mesh was placed beneath each of the trees involved in the integrated field needle compositon study at approximately two-thirds of the crown radius out from the stem. In 1974, four trees were tagged at each of two locations in the University of California Blodgett Experimental Forest, El Dorado County, California. They were tagged GR 1-8, and each received a nylon mesh square prior to litter-fall in 1974 and 1975. In 1975, four Jeffrey and four ponderosa pines were selected for study and tagged GR 9-16 on the Stanislaus National Forest, near Pinecrest, California. Each received mesh squares prior to litter-fall in 1975. It was felt that pine stands outside the SBNF must be considered for comparison in terms of air pollution impact. Having separated annual increments of litter-fall in this manner, we collected periodic samples of litter from these nets, surface-sterilized them, and incubated them on water agar in petri dishes. The populations of microorganisms were then recorded.

To determine the succession of microrganisms on living pine needles, the lowest healthy twigs on the north, south, east and west sides of the stem were clipped not only from trees involved in the integrated field needle decomposition study, but also from trees at Blodgett and Pinecrest. The annual needle increments on each twig were separated in the field. A subsample of each increment was surface-sterilized and incubated on water agar in petri dishes. The populations of microorganisms were then recorded.

For the purposes of this study, a community will be considered to consist of the microbial population inhabiting (1) the needles of a given age on a given twig, or (2) the needles representing a single annual increment of litter-fall beneath a specific tree. Each community will be characterized by an ordered pair of values (S, E) representing taxonomic richness and evenness (Williams, 1977) and a "species" list ranked by abundance. Taxonomic richness is represented by the number of taxonomic categories isolated from each community. Taxonomic evenness is defined as the distance from the point of perfect evenness to the point represented by a given community in n-space. Figure 47 illustrates the concept of evenness in a three species community. Mathematically,

$$\varepsilon = 1- \frac{S \sum_{i-1}^{S} i^{2} - 1}{S-1}$$, where

S = the number of taxonomic categories ("species") in the community, and

π = the species frequency vector such that $\sum_{i=1}^{S} = 1$.

This degree of data summarization will permit comparison of similar communities in different situations.

Laboratory tests of the effect of oxidant dose on decomposers and decomposition--This phase of the project is designed to determine who air pollution affects (1) growth and reproduction of microbial agents of litter decomposition, and (2) rates of needle decomposition by major microorganisms.

Two clear and twelve opaque plexiglass fumigation chambers were constructed and installed inside two walk-in Percival growth chambers on the Oxford Tract, UCB. These walk-in chambers have been renovated to permit control of light, temperature, and relative humidity. The plexiglass chambers permit control of ozone concentration.

Species of fungi isolated from litter samples will be fumigated at a number of ozone concentrations. The fungus will be inoculated onto sterilized pine needle sections placed on cellophane-covered cellulose agar (Eggins and Pugh, 1962) in petri dishes. The effects of ozone on such factors as (1) colony growth rate, (2) spore production, (3) spore germinability, and (4) cellulose decomposition will be quantified.

The ability of a microflora to affect decomposition might be altered by oxidant air pollution. To test this possibility, preweighed, sterilized pine needles from the Sanislaus N.F. were inoculated by placement on a mixture of the organic horizons from BF, CAO, COO, HV, and the Stanislaus N.F. Moistened by constant subirrigation, one-half of the experiment was exposed to ozone-enriched air. Weight loss was determined after 14 weeks.

Over a prolonged period of exposure, microbial populations might be altered by oxidant air pollution in ways which affect their ability to

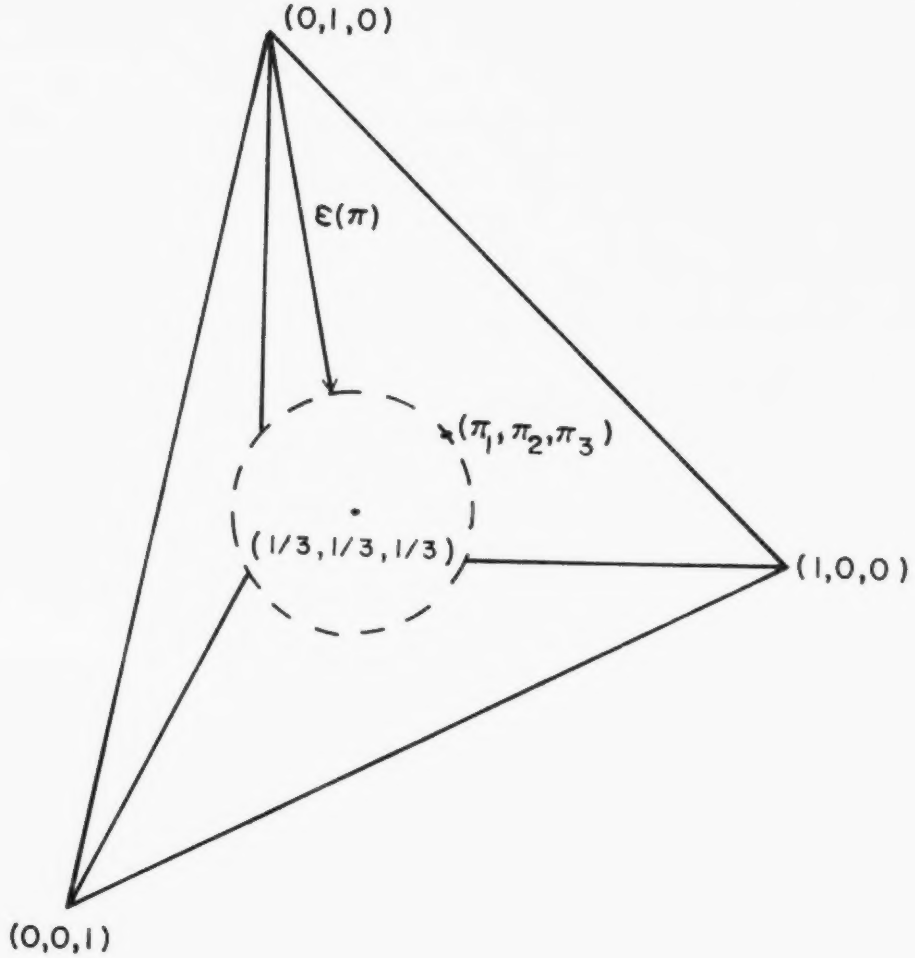

(0,1,0)
ε(π)
(π1, π2, π3)
(1/3, 1/3, 1/3)
(1,0,0)
(0,0,1)

Figure 47. Evenness (ε) in a three species community.

decompose litter. In this experiment, preweighed sterilized pine needles from the Stanislaus N.F. were inoculated by placement on mixtures of the organic horizons from BF, CAO, COO, HV or the Stanislaus N.F. Moistened by subirrigation, the entire experiment was conducted in filtered air. Weight loss was determined after 22 weeks.

Experiments have been designed which will test (1) the ability of a diverse microflora to decompose needles produced by healthy and diseased trees and (2) the effects of moisture and temperature on litter decomposition.

Results and Discussion

Needle Litter Decomposition in Natural Stands--

Quantification of integrated needle litter decomposition in the field has been concluded. Data sets are complete for weight losses incurred by 320, 320, 160, 320 mesh litter envelopes over two years, one year, one winter and the next winter, respectively. The 32 treatments involved in each of these experiments are diagrammed in Figure 45. The 32 interspecific treatments involved in the second overwinter experiment are diagrammed in Figure 46.

Ponderosa pine litter lost more weight ($\alpha = 0.001$) during the two year, one year, and first overwinter experiments than did Jeffrey pine litter (Figure 48). Within each species, greater weight loss occurred on the site receiving the greatest oxidant air pollution dosage.

To determine whether the difference in decomposition rate between ponderosa and Jeffrey pines was due to some species-specific factor or an environmental factor, litter envelopes were placed on plots of the opposite species to decompose. Data from this overwinter experiment (Fig. 49) showed that the species and source of litter was not significantly related to decomposition while the site of decomposition was. It is felt that the overwinter weight losses experienced in these experiments were relatively light, probably reflecting the below-normal precipitation. The sparse literature relevant to this point suggests that weight and nutrient losses by pine needle litter during its first winter on the ground are relatively great (Stark, 1972, 1973; Millar, 1974).

Change in nutrient status (per cent N, P, K, Ca, Mg on a dry weight basis) has been calculated for a pooled sample from each treatment in the two year, one year, and first overwinter experiment. Though both species ultimately gained calcium and nitrogen, ponderosa pine litter consistently acquired both nutrients at a greater rate than did Jeffrey pine litter. This may correspond to the greater fungal activity and subsequent decomposition observed in ponderosa pine litter.

Measurement points at HV received the greatest total daily radiation and temperature input (Table 54), while those at COO received the least. CAO and BF lie intermediate, CAO received more radiation but approximately the same temperature input as BF. This gradient matched the oxidant air

JEFFREY PINE			PONDEROSA PINE		
CAMP OSCEOLA -MODERATE		HOLCOMB VALLEY -HEALTHY	CAMP OONGO -SEVERE		BARTON FLATS -MODERATE
	2 YEARS			2 YEARS	
10.84	>	9.41	19.99	>**	14.64
	1 YEAR			1 YEAR	
11.61	>*	9.43	14.61	>*	11.62
	0.5 YEAR			0.5 YEAR	
2.80	>	2.10	8.86	>**	5.79

Figure 48. Percent weight loss (30 C) incurred by needle litter on four plots, representing the range of air pollution impact on ponderosa and Jeffrey pine. *-significant at 10% level; **-significant at 5% level; and ***-significant at 1% level.

JEFFREY PINE		PONDEROSA PINE
	0.5 YEAR	
HV COO (8.85)		BF COO (9.86)
BF (3.69)		BF (4.27)
CAO (7.08)		CAO (6.40)
HV (4.07)		HV (4.27)
CAO COO (8.89)		COO COO (9.60)
BF (3.57)		BF (5.57)
CAO (3.58)		CAO
HV (2.45)		HV (5.27)

Figure 49. Percent weight loss (30 C) incurred by needle litter following transfer between and within species. Transfers made according to plant shown in Figure 48.

TABLE 54. ESTIMATED TOTAL RADIATION (R) AND TEMPERATURE (T) ACCUMULATED DURING ONE CLEAR DAY AT MEASUREMENT POINTS BENEATH THE INTEGRATED FIELD DECOMPOSITION STUDY TREES.

Species	Plot	Tree	R	T
Jeffrey	HV	1537	107.53	15724.4
		1561	292.14	22919.4
		1574	253.91	21113.6
		1598	400.57	24984.1
		$\bar{x}$	263.54	21185.4
Jeffrey	CAO	1865	167.59	16755.5
		1934	213.93	18626.5
		1964	211.12	15466.0
		807	159.14	15750.0
		$\bar{x}$	187.95	16649.5
Ponderosa	BF	2600	182.03	15988.9
		2625	258.96	20362.2
		2755	126.06	14181.12
		$\bar{x}$	189.02	16844.08
Ponderosa	COO	852	202.04	17864.9
		875	158.33	17477.1
		894	79.47	13917.4
		449	133.44	16978.6
		$\bar{x}$	143.32	16559.5
	$\bar{x}$		166.17	16701.8

pollution, decomposition and species gradients determined for these four plots. This suggests that radiation (and temperature) might be inversely correlated with weight loss. Correlation analysis, however, showed that the only significant within-plot relationship ($\alpha = 0.05$) between litter weight loss and either radiation or temperature occured at HV. Further, at HV litter weight loss was directly proportional to both incident radiation and temperature. The elevation of HV is the highest of the four plots studied and depends heavily on winter precipitation for moisture. Perhaps points receiving greater radiation at HV were exposed for a greater length of time to temperature and moisture conditions conducive to decomposition.

Decomposer Microorganism Populations on Pine Needles in Natural Stands Experiencing Different Oxidant Doses--

One complete experiment during late summer of 1975 provided information on microbial succession in pine foliage in the SBNF, Blodgett Forest, and the Stanislaus N.F. Data from a similar experiment in the SBNF during spring, 1976, will be analyzed shortly. One additional experiment of this type is in progress. In this experiment, it is hoped that nutrient status will be determined by Drs. Arkley and Gersper for each annual increment of foliage. Results of the first experiment are tentative, requiring further analysis and confirmation. Collection of data on microbial succession in litter continues. The value of the data increases from each successive sampling; there are now four annual increments of litter-fall separated (except where nets have been vandalized) in the SBNF. All data collected from these studies will be interpreted in the light of the existing environmental data.

Through the study of annual increments of living foliage and stratified litter, successions of microfloral populations are being determined for individual trees representing plots and regions impacted by varying amounts of smog. Comparisons among these population successions will help to explain patterns in (1) litter decomposition and (2) the incidence of fungus-caused damping-off of pine seeds and seedlings (under study by the seedling establishment investigators). Species of fungi for which population data have been collected, to date, include phycomycetes, ascoymcetes, basidiomycetes, and fungi imperfecti. A method for the culture of fungi on microscope slides has been employed for the grouping and identification of important isolates (Riddell, 1950).

Laboratory Tests of the Effect of Oxidant Dose on Decomposer and Decomposition--

Two growth chamber decomposition experiments have been completed. The data from these experiments will be analyzed shortly and both will be repeated. The first experiment tested the ability of BF, COO, CAO, HV, and Stanislaus N.F. litter microorganisms to decompose a standard sterile needle litter in filtered air. The second experiment tested the effect of ozone on the decomposition of standardized litter by the organisms in a standardized mixture of the organic horizons from BF, COO, CAO, HV and the Stanislaus N.F.

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APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES.

Dataset name	Definition of data content
SBNFPUBS	Bibliography of publications, manuscripts in preparation, and intended manuscripts from scientists conducting research under EPA contracts 68-02-0303, 68-03-0273, 68-03-2442, R805410-01 from 1972 through present.
PLOTINDX	For each vegetation plot, gives year established, elevation, geographic coordinates, length, width, azimuth, general hillslope aspect, tree tag colors, lowest and highest tree tag numbers, forest type, and number of tagged trees;
SXSCAT	Soil exchangeable and soluble cations, various soil depths on each vegetation plot;
STEXOM	Soil texture and organic matter; percent of soil in various texture classes, pH, and organic carbon and nitrogen content at various depths on each vegetation plot;
TREE	Tree identification; locations and species of tagged trees on each vegetation plot;
STAGE	Stand age data; number of trees by ten year age class, by species, on vegetation plots;
SHRUB	Locations of shrub cover, by species, along a transect across each vegetation plot;
TREEVEG	Tree vegetation data; density, basal area, species composition of trees, greater than, or equal to 10 cm diameter at breast height, on each vegetation plot;
SHRUBVEG	Shrub vegetation data; frequency, density, percent cover, by species, on each vegetation plot;
PLOTREGN	Plot regeneration data; age of tree seedlings, saplings, poles, and age classes of trees in larger size-classes, by cover types, on each vegetation plot;
FIRETREE	Tree data on 85 special study plots which had burned at various dates;
FIRESTAG	Fire stand age data; similar to STAGE (above) but on 85 special study plots which had burned at various dates;

APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES. (CONTINUED)

Dataset name	Definition of data content
FIRESHRUB	Fire shrub data; similar to SHRUBVEG (above), but on 85 special study plots which had burned at various dates;
CTREE	Crown tree data, such as Keen crown class, crown position in canopy, gross geometrical crown volume, tree height, and crown ratio, for each tagged tree on each vegetation plot;
FSMTINDX	Forest Service meteorological data index; days, by month and year, in FSMET dataset, which have valid usable data;
FSMET	Forest Service meteorological data which were telemetered from 3 sites near the vegetation plots; net radiation, air temperature at 4 ft and 6 ft, relative humidity, wind direction, wind speed, hourly resolution;
HMET	Historical meteorological data, incuding relative humidity, wind direction, wind speed, air temperature maximum and minimum on a daily basis, for sites at various distances from vegetation plots;
HPREC	Historical precipitation data on monthly and annual basis for 23 sites operated by the San Bernardino County Flood Control District, and ranging as far back as 92 years;
OXIDINDX	Oxidant index; days, by month and year, which have valid data in OXIDANT dataset;
OXIDANT	Hourly data on oxidant and ozone concentration at sites in the vicinity of vegetation plots;
PLOTMET	Plot meteorological data on air temperature and relative humidity from hygrothermographs located on the vegetation plots;
PLOTPREC	Plot precipitation data from snow gauges and summer rain gauges located on each vegetation plot;
PLOTOXID	Plot oxidant ambient concentration data obtained during various time periods on vegetation plots;
OZFLUX	Ozone flux data for sample conifer trees near a vegetation plot;

APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES. (CONTINUED)

Dataset name	Definition of data content
STOMRES	Stomatal resistance data for sample conifer trees near a vegetation plot;
INJBIWK	Air pollution- conifer tree foliar injury on a biweekly basis for sample trees near a vegetation plot; needle retention, needle length, injury length;
TREE	Annual foliar injury observations on each tagged tree on each vegetation plot; needle retention score, needle condition score, branch mortality score, needle length score, total smog injury score, disease observation, insect risk category, tree diameter at breast height;
TREEMORT	Tree mortality data for each vegetation plot;
SAPTREE	Sapling tree data, analogous to the tree dataset (above), but for sapling plots located very near the vegetation plot;
SAPGRO	Sapling height growth data on an annual basis on the sapling plots;
SAPSURF	Sapling foliage surface data;
PNFALL	Pine needle fall from tree crowns on an annual basis, beneath selected pine trees on all but 2 of the vegetation plots;
TREELIT	Tree litter thicknesses on the ground in 4 directions at various distances from the tree trunk, under selected trees on selected plots;
PLITR	Plot litter thickness at 2 m intervals down the centerline of each vegetation plot in 1973;
LITMAS	Litter mass (dry weight) at various distances from trunks of selected trees on selected vegetations plots;
TREEGRO	Tree growth data, cumulative radial, for conifer trees at least 10 cm diameter, breast height, on 6 vegetation plots representing extremes of air pollution exposure;
TREESOIL	Soil type, hillslope gradient, and hillslope aspect for each tree in the TREEGRO dataset;

APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES. (CONTINUED)

Dataset name	Definition of data content
TREEGRO2	Amalgamation of TREESOIL dataset with TREEGRO, and converted to give annual radial stem growth, at breast height, as far back as year 1920;
BOGRO	Black oak growth data, similar to TREEGRO dataset described above;
MOIST	Soil water percentage, by weight, at various depths at weekly, or biweekly, intervals for 22 sites, including the vegetation plots;
MATRIC	Soil water MATRIC potential at various depths for data from the MOIST dataset, converted by means of soil water retention curves determined in the lab, using respective field soil samples;
ISURV	Insect survey data taken in early summer and late fall, from tagged trees on vegetation plots;
BTREE	Beetle tree data; infestation heights and stem circumferences at sampling heights for western pine bark beetle on killed trees;
EGG	Western pine bark beetle attack densities, gallery lengths, egg counts, from bark disc samples off of killed trees;
REAR	Emergent bark beetle densities, parasites, and predator data from bark field samples reared under laboratory conditions;
STIK	Emergent bark beetle densities, parasites, and predator data from bark into sticky cartons on tree trunks under field conditions;
XRAY	Potential bark beetle brood, as determined from XRAYs of bark sample discs;
DISU	Disease survey data; plant diseases found on tagged trees on vegetation plots;
FASP	_Fomes_ _annosus_ spread plots data;

APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES. (CONTINUED)

Dataset name	Definition of data content
SPRMORT1	Super plot mortality dataset #1; data on dead and severely damaged trees, obtained in cooperation with the Pest Damage Inventory, U.S. Forest Service, Region 5, San Francisco;
SPRMORX	Super plot mortality extra data not part of the USFS/PDI (above); smog score components, basal area detail, additional insect related symptoms, recent annual stem radial growth rate, height to lowest live branch bearing needles, all on dead/damaged tree mortality centers;
STNDSITE	Stand site data for trees around each dead/damaged tree mortality center in a superplot;
TREEPEST	Tree morphological and growth data, and insect and disease data, for each tree in the stand surrounding a mortality center;
SPRXTREE	Super plot extra tree data for trees within a 30 m x 30 m plot around each mortality center;
SPRXRGNS	Super plot extra regeneration tree data in square plots (10 m x 30 m) upslope from each mortality center;
SPRXRGNC	Super plot extra regeneration tree data in circular plots (6.5 m diameter) around mortality centers and paired living trees;
SPRXGRND	Super plot extra ground cover data in 3 plots (10 m x 30 m) upslope from each mortality center;
SPRXSHRB	Super plot extra shrub intercept data along 2 lines (30 m) upslope from each mortality center;
SPRMORT2	Super plot mortality dataset #2; data on dead and damaged trees obtained from superplots located near air quality and meteorological monitoring sites; done separately from SPRMORT1 (above);
CONE	Annual cone counts from trees on vegetation plots;
PLOTSEED	Average seed production per cone for cone-bearing trees on each vegetation plot;

APPENDIX 1. PART II OF THE SBNF DATA DICTIONARY: DEFINITION OF DATASET NAMES. (CONTINUED)

Dataset name	Definition of data content
SAPS	Seedling air pollution study; numbers of emerged pine seedlings and seedling mortality from various ground cover and wildlife exclusion treatments in mini-plot on selected vegetation plots;
LSOIL	Laboratory determined soil moisture percent by weight for soil samples taken from seedling mini-plots;
SSAS	Seedling supplementary animal study; data on proportional loss of seeds and seedlings associated with different kinds of wildlife exclusion treatments in mini-plots on select vegetation plots;
SLSS	Supplementary litter seedling study; data on seedling emergence and mortality associated with different litter depth treatments;
FLDECOMP	Field decomposition data for pine needles in net bag samples under select trees on select vegetation plots, over 1, 2, and 3 year intervals;
LITRKEM	Litter chemistry; elemental content of pine needle fall at various distances from tree stems, beneath select sample trees on select vegetation plots;
DRIP	Intercepted precipitation crown drip elemental content, at various distances from tree stems, beneath select sample trees on select vegetation plots;
SFCSOLKM	Surface soil chemistry; elemental content of surface soil at various distances from tree stems, beneath select sample trees on select vegetation plots.

APPENDIX 2. ON-LINE DATASET PROGRESS CHECKLIST FOR SBNF DATA BASE OF AUGUST 31, 1977.

IDENTIFICATION			NEW DATA			VERIFICATION				ANALYSIS		INFORMATION TRANSFER		
DATASET NAME	PRINCIPAL INVESTIGATOR	DATA (MONTH) YEAR	DATA FORM FORMAT APPROVED?	DESCRIPTOR ENTERED?	KEYPUNCHED?	UNVERIFIED DATA ENTERED?	VERIFIC PROGR DEBUGGED?	DATA LISTING TO P.I. (DATE)	CORRECTIONS ENTERED?	REDUCTION PLAN DEFINED?	REDUCT PROGR RAN?	ANALYSIS OUTPUT TO P.I.?	MODEL DOCUMENTATION UPDATED?	WRITTEN INTERPRETATION RECEIVED
SBNFPUBS	PROJECT	---	-----	Y	N	---	---	-------	---	-----	---			
PLOTINDX	PROJECT	ONCE	-----	Y	Y	---	---	-------	Y	-----	---			
SXSCAT	ARKLEY	ONCE		.	.	Y		Y	N	N				
STEXOM	ARKLEY	ONCE		.	.	Y		Y	N	N				
TRID	MCBRIDE	ONCE/73		N	.	Y		5/77						
STAGE	MCBRIDE	ONCE		N	N	10/77								
SHRUB	MCBRIDE	ONCE		N	N									
TREEVEG	MCBRIDE	ONCE		N	RPT									
SHRUBVEG	MCBRIDE	ONCE		N	RPT									
PLOTREGN	MCBRIDE	1977	Y	N	12/77									
FIRETREE	MCBRIDE	ONCE		N	N									
FIRESTAG	MCBRIDE	ONCE		N	N									
FIRESHRUB	MCBRIDE	ONCE		N	N									
*CTREE-FD	LUCK	ONCE/75	-----	Y	M10	UCR		AT UCR	M10	-----				
CTREE- RD	LUCK	ONCE/75	-----	Y	M10				N10	N				

APPENDIX 2. ON-LINE DATASET PROGRESS CHECKLIST FOR SBNF DATA BASE AS OF AUGUST 31, 1977 (CONTINUED).

FSMTINDX	MILLER		-----	N	N									
FSMET	MILLER	75-76		N	Y	Y	---	AT UCR	Y	N				
HMET	MILLER	73-76		N	.	.	---	AT UCR	Y	N				
HPREC	ARKLEY	TO 9/75	Y	N	.	.	---	.	Y	N				
		10/75-9/77			N	UCR		AT UCR	UCR					
OXIDINDX	MILLER		-----	N	N	---	---	-------	---					
OXIDANT	MILLER	1967-76		N	.	.			Y	N				
PLOTMET	MILLER	MAY 77	N	N	N	UCR		AT UCR						
PLOTPREC	MILLER	WINTER75		N	.	.			Y	N				
		WINTER76			.	.			Y	N				
PLOTOXID	MILLER	MAY 77	N	N	N									
OZFLUX	MILLER	JUN 77	N	N	N									
STOMRES	MILLER	?	N	N	N									
INJBIWK	MILLER	JUN 76	N	N	Y	UCR		AT UCR	N					
		77		N	N	UCR		AT UCR						
TREE	MILLER	FALL73		N	Y	UCR	---	AT UCR	N	N				
		74			Y	UCR	---	AT UCR	N	N				
		75			Y	UCR	---	AT UCR	N	N				
		76			Y	UCR	---	AT UCR	N	N				
		77			N	UCR	---	AT UCR	N					
TREEMORT	MILLER	?	N	N	8/77	UCR		AT UCR						
SAPTREE	MILLER	ONCE	N	N	N	UCR		AT UCR						
SAPGRO	MILLER	1967-76		.	.	UCR	---	AT UCR	Y	N				
SAPSURF	MILLER	77	N	N	9/77	UCR	---	AT UCR	UCR					
PNFALL	ARKLEY	73&74		.	.	Y		Y	N					
		75		Y	N	N	N	N						
		76		Y	N									
		77		Y	N									
TREELIT	ARKLEY	73/75		N	.	Y		Y	N					
PLITR	ARKLEY	ONCE 73		N	.	Y		Y	N					
LITMAS	ARKLEY	73/74		N	.	Y		Y	N					
*TREEGRO	OHMART	TO8/76	.	.	.	.	.	.	.	.	Y	-------		
		TO8/77			N	N	N				Y	-------		

APPENDIX 2. ON-LINE DATASET PROGRESS CHECK LIST FOR SBNF DATA BASE AS OF AUGUST 31, 1977 (CONTINUED).

*TREESOIL	OHMART	ONCE	.	.	.	.	.	.	.	.	Y	------		
TREEGRO2	OHMART	T08/76	.	.	.	.	.	.	.	.	Y	SOME	6/77	
		T08/77			N	N	N							
*BOGRO-FD	LAVEN	12/77	.	Y	N									
*CMOIST	ARKLEY	ONCE		.	.	.	.		Y	Y				
*POINTS	ARKLEY	ONCE	-----	.	.	.	.		Y	Y				
*GRAV	ARKLEY	?		N	N									
*MOIST-FD	ARKLEY	73-76	-----	.	.	.	.		Y	Y				
		77		---	N	N	---		Y	Y				
MOIST-RD	ARKLEY	73-76		.	.	.	Y	10/77	N	N				
		77		Y	N	N	N		N	N				
*H2OCURVS	ARKLEY	ONCE		.	.	.				Y	N			
MATRIC	ARKLEY	73-76		N	N									
ISURV	DAHLSTEN	73		N	.	.	.	.	Y	N				
		74			.	.	.	.	Y	N				
		75			.	.	.	.	Y	N				
		76			.	.	.	.	Y	N				
		77			N	N								
BTREE	DAHLSTEN	73-1/2		N	Y			.	.	Y	?			
		74-1/2			Y			.	.	Y	?			
		75-1/2			Y			.	.	Y	?			
		76-1/2			Y			.	.	Y	?			
EGG	DAHLSTEN	73-1/2		N	Y			.	.	Y	?			
		74-1/2			Y			.	.	Y	?			
		75-1/2			Y			.	.	Y	?			
		76-1/2			Y			.	.	Y	?			
REAR	DAHLSTEN	73-1/2		N	Y			.	.	Y	?			
		74-1/2			Y			.	.	Y	?			
		75-1/2			Y			.	.	Y	?			
		76-1/2			Y			.	.	Y	?			
STIK	DAHLSTEN	73-1/2		N	Y			.	.	Y	?			
		74-1/2			Y			.	.	Y	?			
		75-1/2			Y			.	.	Y	?			
		76-1/2			Y			.	.	Y	?			

APPENDIX 2. ON-LINE DATASET PROGRESS CHECKLIST FOR SBNF DATA BASE AS OF AUGUST 31, 1977 (CONTINUED).

XRAY	DAHLSTEN	73-1/2		N	Y			.	.	Y	?			
		74-1/2			Y			.	.	Y	?			
		75-1/2			Y			.	.	Y	?			
		76-1/2			Y			.	.	Y	?			
DISU	COBB	JUN 74		N	.	.	Y	4/77	N	N				
		JUN 76			.	.	Y	4/77	N	N				
FASP	COBB	?	10/77	N	N	N								
SPRMORT1	MCB/D/C	76		Y	.	.	---	Y	?	N				
		77		N	N	N								
SPRMORX	MCB/D/C	77		N	N	N								
STNDSITE	MCB/D/C	77		N	N	N								
TREEPEST	MCB/D/C	77		N	N	N								
SPXTREE	MCBRIDE	77		N	N	N								
SPRXRGNS	MCBRIDE	77		N	N	N								
SPRXRGNC	MCBRIDE	77		N	N	N								
SPRXGRND	MCBRIDE	77		N	N	N								
SPRXSHRB	MCBRIDE	77		N	N	N								
SPRMORT2	MCB/D/C	76		Y	.	.	---	Y	?	N				
		77?		N	N	N								
CONE	LUCK	73-76		.	.	UCR	---	AT UCR	Y	N				
	.	77			N	UCR		AT UCR	UCR					
GCONE	LUCK	SPRING78		N	N	UCR	---	AT UCR	4/78					
PLOTSEED	LUCK	76		N	RPT									
SAPS	COBB	77	Y	N	N	N								
LSOIL	COBB	77	N	N	N	N								
SSAS	COBB	77	Y	N	N	N								
SLSS	COBB	77	Y	N	N	N								
FLDECOMP	PARMETER	?	N	N	N	N	N							
LITRKEM	ARKLEY	73-75		N	Y	Y		Y	N	Y	N			
		76??			N	N								
DRIP	ARKLEY	74-75		.	.	.		Y	N	Y	N			
SFCSOLKM	ARKLEY	75		N	Y	Y		Y	N	Y	N			

APPENDIX 2. ON-LINE DATASET PROGRESS CHECKLIST FOR SBNF DATA BASE AS OF AUGUST 31, 1977 (CONTINUED).

LEGEND FOR HEADINGS:

"VERIF PROGR" IS VERIFICATION PROGRAM (COMPUTER),
"P.I." IS PRINCIPAL INVESTIGATOR,
"REDUCT PROGR" IS (DATA) REDUCTION PROGRAM (COMPUTER),

LEGEND FOR COLUMN ENTRIES:

"*" PRECEDING DATASET NAME INDICATES ORIGINAL DATA USED TO DERIVE SUBSEQUENT DATASET, SO ORIGINAL MAY NOT BE DIRECTLY MEANINGFUL TO OTHER INVESTIGATORS.
"N" IS NO; THIS NEEDS TO BE DONE, BUT HAS NOT BEEN COMPLETELY FINISHED YET (AS FAR AS IS KNOWN),
"Y" IS YES, THIS STEP HAS BEEN ACCOMPLISHED,
"RPT" MEANS THAT THIS IS TO BE GOTTEN OUT OF AN EXISTING REPORT,
"?" MEANS THE STATUS OF THE INFORMATION ITEM HAS NOT BEEN DETERMINED YET,
"ONCE" MEANS THE DATA ARE ONLY COLLECTED ONCE, NOT REPEATEDLY,
"UCR" MEANS THAT THIS STEP IS BEING HANDLED AT THE UC RIVERSIDE CAMPUS,
"8/77" IS THE APPROXIMATE DATE WHEN THE P.I. PLANS TO COMPLETE THE STEP,
"M10" MEANS THAT DATA FOR SOME PLOTS HAVE BEEN RECEIVED, BUT WE ARE STILL "MISSING 10" PLOTS' DATA WHICH P.I. IS STILL PROCESSING,
"." MEANS PROGRESS HAS GONE BEYOND THIS STEP; LOOK AT COLUMNS TO THE RIGHT--->
"---" MEANS THIS STEP IS NOT APPLICABLE IN THE MODELLING/DATA MGMT SUBPROJECT; BEING DONE ELSEWHERE.